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CAUSE FACTOR:HUMAN

A Treatise on Rotary Wing Human Factors

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A Treatise on Rotary Wing Human Factors

By
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with contributions by
Hugo Leech

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THIS BOOK IS DEDICATED TO

KEN YOUNG - A GREAT HELICOPTER PILOT -

AND TO HELICOPTER PILOTS EVERYWHERE

ALSO TO DAVE GITTEL AND OTHER

FALLEN FRIENDS

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FOREWORD

This manuscript was prepared in the interests of helicopter safety. The aims are threefold:

1. To inform those involved in helicopter operations, construction and design about some of the human factor problems associated with rotary wing flight.

2. To inform such medical people as Aviation Medical Officers and Flight Surgeons of some of the basic principles of helicopter flight and a few of the human factor problems related to this form of transport.

3. To stimulate interest in research into human factor aspects which may compromise the safety of helicopter operations.

Perhaps one of the most interesting facets of aviation medicine is a philosophical one: in studying the relationship between man and his creations, one comes to understand more about man. Much of this information can be applied to other areas of endeavour. Wilbur Franks, who is considered by many to be the father of aviation medicine in Canada, and who invented the original G suit, has stated that we are experiencing one of the worst pandemics the world has ever known: the transportation accident. Many of the elements which could go into improving this dreadful picture of injury, death and sorrow can be learned by studying other areas of the critical relationship between man and machine. The high profile of aviation accidents has provided us with the resources to study these in some detail.

As an undergraduate student, I was interested in entering a field of biological science which studies marine animals. I was also interested in medicine and approached a professor and asked him what he thought about going into medicine. The reply was that it pays great dividends to learn as much as possible about at least one organism, thereby providing a base for comparison of others and, therefore, any knowledge that was picked up in medical school would certainly be of great value in any subsequent study of biology, should I decide to enter medical school. This philosophy can also be applied to this particular book. I have tried to provide a more detailed insight into the operation of the helicopter as a machine, the operating environment, and aspects of human behaviour as applied to the above, hoping to provide one with some detailed knowledge of at least one man-machine interface. It is hoped, therefore, that even if one is not particularly interested in helicopter operations, he may pick up knowledge that can be applied to other areas of human performance.

I would like to thank the many people who stimulated and assisted me in amassing this data. Recognition is given to Colonel A.K. Casselmann, formerly of the Canadian Armed Forces, the members of the Rotary Wing Squadron at CFB, Portage la Prairie, and to my helicopter instructor, Major Tommy Thompson. I also wish to thank those in Transport Canada, particularly Mr. Dick Peters, who offered help and criticism in the preparation of this paper, and to Hugo Leech, who is a contributor. Dr. Ian Anderson, Director, Civil Aviation Medicine, of the federal Department of National Health and Welfare deserves special thanks for his encouragement and criticism. Lois Parent, who patiently and diligently typed the manuscript, also deserves my thanks.

Much credit is given also to the many authors and investigators from whose work most of this material is derived. Many of them have dedicated their academic careers to improving the safety of this remarkable vehicle, the helicopter.

The objectives of this book are as stated above and do not represent or reflect any policy of the Department of National Health and Welfare, Transport Canada or the Canadian Armed Forces.

Olaf W. Skjenna, M.D., D.Av.Med.

CHAPTER I

THE SCENE

September 6

For the twenty-third straight day, moisture-laden Pacific air pressed up the Coast Mountains on prevailing westerly currents. Nearing the summits of the passes, the air cooled to the supersaturation point, forming fog and then giving birth to large damp snowflakes which filled the air like a million albino moths. The temperature was 0C.

Photo 1-1

Bill T, a pilot with 29 years of experience, sat impatiently in the chopper waiting for his engineer. With some misgivings, he peered up the slope into the increasing gloom and cursed the weather. In two and one-half months, there had only been four sunny days. The camp was a muddy quagmire and the dampness and cold had penetrated everywhere, making life miserable. But drilling companies can't hold up exploration for a little sour weather, and helicopter pilots don't have much time to bemoan the lack of creature comforts.

A sudden movement and the engineer appeared from the mist, opened the door and climbed in. In less than four minutes, Bill and his engineer would be tumbling down a mountainside in a burning wreckage.

"OK. 3100 RPM. Carb heat full on. Plenty of torque if we stay low. I'll be able to find our way to the saddle if I just keep our speed down and the slope in sight."

Inching up the slope to the 8000-foot saddle pass, Bill was irritated to see his bubble begin to fog up but was at the same time relieved to observe that at least there was no ice forming on the outside, indicating that the rotors weren't icing (or so he thought - forgetting momentarily that this indicator works only at cruise speed).

Up the slope they continued, pressing on through the fog, mist and swirling snow, sometimes remaining motionless and waiting for a glimpse of ground to give them a bearing. Bill was sweating.

Finally, flat terrain. Must be the saddle. Inching forward, he could see the ground falling away, starting its 35 degrees to the base of the mountain and the drilling site located three thousand feet below. Neither man could see into the valley, however. Bill inched the machine forward.

"No!! RPM decreasing!! Got to put her down!! Can't!! Too much slope!!" Bill had the throttle cranked wide open, but the RPM's kept dropping.

Adrenaline surging through a person's body has many effects. It can give you unknown strength or agility. For some, like Bill, it makes time seem to come to a standstill so that events which happen in a few seconds seem to stretch on forever, like in a slow motion film.

There was no way out now. The only hope was to try to accelerate down the slope and achieve translational lift. "We'll just have to go", Bill shouted to the engineer as he eased the cyclic forward and they hurtled down the slope about a foot off the snow.

Glancing at the panel just before the first impact he noted an RPM of 2500, and the airspeed needle wavering in the 20 MPH range. Then, a heavy thud and a cacophony of noise as the main rotor slammed into the boom, severing the myriad of tubes and the shaft driving the tail rotor.

The machine gyrated wildly as if in some sort of frenzy, and then struck a second time. Bill watched the bubble shatter and disappear and felt multiple stings as shards of plexiglass buried in his face. He even noted the sudden fresh odour as clear mountain air replaced the stuffy air in the bubble. In a terrifying instant the snowy landscape lit up with a bright orange flash and Bill knew they were on fire. Every pilot has secret nightmares of being trapped in a burning airplane, and Bill was no exception. His heart pounded wildly as he felt the searing heat on the right side of his face, and the nightmarish glow disclosed the destruction taking place around him as the machine thrashed itself to death.

Suddenly, Bill was aware of a peaceful quiet as can only be experienced in the high mountains - perfect stillness except for a crackling sound behind him which he quickly realized was the sound of fire.

"Got to get out". He undid his belt and crawled out through the front of the machine and ran along the slope. Remembering the engineer, he turned around in time to see

him emerging from the flames. As he approached, Bill noticed that his hair was matted from what looked like mud - it was singed from the fire.

Together they sat on the slope and watched the wreckage burn.

Photo 1-2

This was a true account of an actual helicopter accident by a pilot who was fortunate enough to survive. Unfortunately, it is a scene which is repeated far too often, frequently with more disasterous results.

Between January 1976 and September 1980 there were 535 helicopter accidents of all types in Canada. This is a very high number when one considers that there were fewer than 900 helicopters registered as of 15 October, 1980. When one examines the accident statistics concerning helicopter pilots it appears that one in four pilots would have an accident within a five-year time period, assuming a uniform apportioning of accidents.

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The majority of accidents are related to human factors, often errors in judgment contributed to by fatigue, task overload, discomfort, misinformation and other factors. Some 80 to 90 per cent have human factors as a direct or contributing cause, while the others are related to materiel failures. In fact, even with these latter accidents an investigator asking his favourite question, "Why?" enough times will inevitably uncover a human factor whether it be in the design, construction or maintenance of the machine. Most of the accidents involve wirestrikes, rotor strikes, snagged skids, overloading, problems caused by wind gusts, and landing on uneven or soft terrain or obstacles. Weather accounted for 29 accidents in the 1976 to 1980 period.

Can pilots like Bill T be blamed for making improper decisions or failing to judge or adequately assess a situation leading to an accident? Aside from the relatively rare cases involving negligence or dereliction of duties, I think not. Helicopter pilots are confronted with a myriad of stresses which may influence their capability to fly a helicopter, and in addition are often immersed in unenviable environments working in close proximity to hazards, and handling a machine which is near the limits of man's capability to fly.

Safe and successful piloting involves the integration of three distinct elements into one overall system - the aerospace system. These elements are the man, the machine, and the environment, the latter including operating conditions as well as meteorological considerations. Each of these elements influences the others to varying degrees and are mutually dependent, also to varying degrees.

Unfortunately, the element which is most vulnerable and susceptable to influence by the other two is also the least understood and most difficult to evaluate. This element is, of course, the man - a fact which should come as no surprise, especially to those involved in the field of human factors. And yet the man is often virtually ignored in design, operating considerations and training.

A pilot during his training spends a considerable amount of time learning about the vagaries of meteorology and about the intricacies of his machine, but precious little is devoted to studying the most vulnerable part of the system - himself. This inadequacy is further compounded by the fact that often one's worst judge is oneself, particularly when it comes to evaluating performance. How depressing it would be to immediately recognize all of one's inadequacies and shortcomings!! Our personalities have developed means of protecting ourselves from such incriminating insight - but this has also created a problem which we must overcome in order to properly evaluate our capability to fly at any given time.

In addition, there is little training aimed at maintaining our capabilities or fitness compared to the amount of information concerning the welfare of our machines. It has often been quoted that people look after their automobiles more carefully and better than they look after their bodies. I am sure that this statement applies to airplanes and helicopters too.

Surely these shortcomings must be overcome. I have concluded from my experience that the most effective way is by informing operators and pilots of some of the pitfalls which may lead to disaster. Pilots should be able to develop some sort of a mental checklist and be able to evaluate themselves quickly and with as little bias as

possible. In order to do this they must know what to expect, and it is to this end that most of this book is dedicated.

OK, we know that despite all reasonable efforts accidents will occur. Therefore, we must dedicate some effort to the protection of occupants, both crew and passengers. A burning wreckage is virtually inexcusable in this modern day. The state of the art exists to protect occupants and prevent fatalities in survivable accidents. Later chapters are dedicated to crashworthiness investigation and evaluation.

What is safety? Some have defined safety as absence of risk, a definition which is absurd in its limitations. Safety is the identification and control of risk according to some preconceived parameters. The amount of risk acceptable at any given time or in any given operation depends upon circumstances at that time. For example, the parameters of acceptable risk will be different for a military operator in peacetime compared to wartime. Likewise, the limits of acceptable risk for a civilian passenger-carrying operator will be different from a pipeline patrol.

It is hoped that this book will be of some assistance in the identification control of various risk factors. It is written with the intention of providing some insight into man's behaviour and capabilities and to describe the demands which may be imposed upon him by the machine. By knowing these factors, and by deciding what the levels of acceptable risk are, an operator may then formulate his own guidelines.

CHAPTER II

FROM THE BEGINNING

"Like all novices, we began with the helicopter (in childhood) but soon saw it had no future and dropped it. The helicopter does, with great labour, only what the balloon does without labour, and is no more fitted than the balloon for rapid horizontal flight. If its engine stops, it must fall with deathly violence, for it can neither float like a balloon nor glide like an aeroplane. The helicopter is much easier to design than an aeroplane, but is it worthless when done."

Wilbur Wright, January 15, 1909

Photo 2-1

1938, Berlin, Germany

It was late afternoon and the crowd in the Berlin Sports Hall was restless with anticipation. They gazed in wonderment at a strange-looking apparatus on the floor in the centre of the hall. Known as the Focke-Achgelis, (Fig. 2-1), it looked not

unlike a conventional airplane, but instead of wings, a supporting structure like a triangular oil derrick was affixed to each side of the fuselage and each supporting a rotor. A wave of excitement rolled across the crowd when the pilot, Miss Hannah Reitsch, strode confidently across the floor and climbed into the cockpit of this strange craft. The crowd fell silent. Soon the stillness in the great stadium was interrupted by the cacophony of a 165 h.p. engine bursting into life, and the propellers on top of each of the derricks began rotating, stirring up the dust from the floor. The great machine began to stir and shift restlessly and then clattered into the air about 15 feet, and hung there as if suspended by cables from the high ceiling. As Miss Reitsch performed some of the hovering maneouvres, the crowd showed its appreciation. But did they really appreciate that they were witnessing the beginning of a new era, the helicopter era.

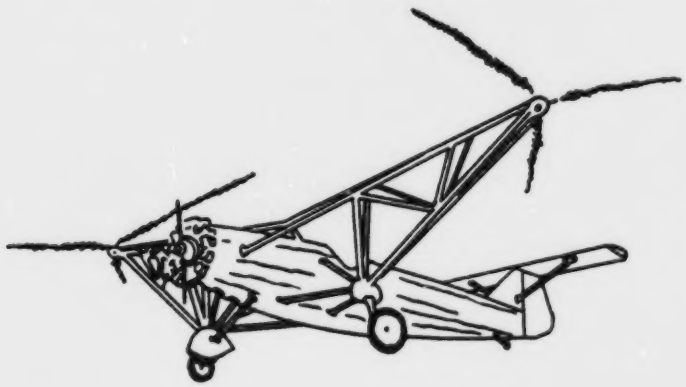


Fig. 2-1 Focke-Achgelis

Hannah Reitsch, who later became Hitler's personal pilot, made many other flights in the Focke-Achgelis, including the first cross-country trip executed by any helicopter, a flight averaging 68 miles per hour from Bremen to Berlin. The unwieldy looking machine created a host of new records. It flew a record trip of 143 miles and rose to an altitude of 11 243 feet. For at least 20 kilometres, it maintained a speed of 76 miles per hour.

Fortunately, the pessimistic uttering of Wilbur Wright, like many of the predictions related to aerospace development, was untrue. Where then, did it all begin, and how did it progress to our present state of the art?

The vision and application of vertical flight goes back beyond recorded time. The boomerang (still used by primitives in Australia and Africa), an example of the helicopter principle, was one of the first weapons in the arsenal of man. The boomerang's ability to spring aloft, to hover, and to descend without injury to itself is an example of the practice of rotor-twirling an auto-rotation. Nature, in machines of its own invention, demonstrated this principle even before the existence of man. Fossils contain the winged maple seeds which, spinning downward on a calm day, are

still a demonstration of proof. The dragonfly in its hover, the bee, and the humming bird as well, with its stationary wing beat of more that 200 strokes per second are equally impressive examples of vertical and hovering flight.

Later, in the early history of man, some of the principles of nature were embodied in "Chinese tops". The Chinese top consisted of a propeller on a stick which was spun between the hands, thereby developing lift. (Fig. 2-2)

A modern plastic version of these tops is a common children's toy.

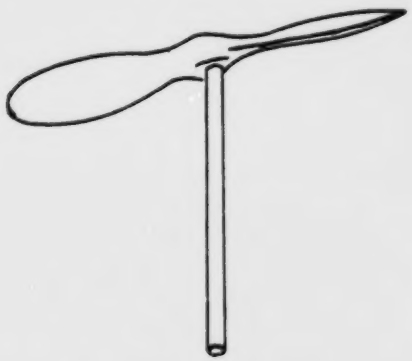


Fig. 2-2 Chinese Top

Nearly three centuries before Christ, the extraordinary Greek, Archimedes, originated a multitude of devices through his diverse expertise in mathematics, physics and invention. He was the inventor of the instrument, the fully-enclosed cylinder inside which a continuous screw forms a spiral chamber and is used to drain water from sunken ships. It is still used for irrigation water lifting in every country in the world and remains the most efficient conveyor of such things as grain, sand, or gravel. Its most important application, however, did not come until nearly 1800 years later, when, Leonardo Da Vinci, at the age of 33, doodled some sketches and notes on the riddle of flight. In 1505, he wrote a monograph on the subject in his secret backward script. Da Vinci saw instantly what Archimedes had never reported: that air and water were elemental first cousins. He maintained that anyone who wanted to study either, would do well to study both.

It was only another step for Da Vinci to prove to himself that the unenclosed Archimedian screw would work in the air as well as water. It needed to be twirled faster in the lighter element, but the lifting result would be the same. Da Vinci described the first theoretical helicopter: "I find that if this machine made with a screw be well made--that is to say, made of linen of which the pores are stopped up with starch--and be turned swiftly, the said screw will make its spiral in the air and it will rise high. When force generates swifter movement than the flight of the unresisting air, this air becomes compressed after the manner of feathers compressed and crushed by the weight of the sleeper. And the thing which drove the air, finding resistance in it, rebounds after the manner of a ball struck against a wall."

Da Vinci became interested enough in his studies to compose a list of supplies needed for the building of such "machines to fly". He produced drawings of what looked like a sled with binding for the flyer as he lay prone, working two crossed rods back and forth like oars.

Another such machine bore a great deal of resemblance to the earliest practical helicopters. It consisted of a system of double fans, worked by an upright man standing in a large bowl and sweating over a system of pulleys. Perhaps Da Vinci did not have as much faith in this gimmick as later historians have ventured to believe. He designed the first parachute of stiffened linen and cautioned any bold pilot to fly over water so he would not be hurt when he fell. His final contribution was the first known aerial chart, a rough drawing of Spain, France and Germany divided into provinces, so that the pilot--if he survived--might know where he was. However, Da Vinci did make some errors in his calculations in that he failed to compare accurately the power to weight ratio of birds with the power to weight ratio of man to realize the necessity for a power plant.

About the same time as Leonardo was writing his treatise on flight, an Italian alchemist, pursuing his studies in an Abbey in Scotland, guaranteed the Monks that he could descend and fly from the precipituous walls of Castle Sterling across the English Channel to France. Actually attempting the feat, he wound up with a fractured femur and established one of the earliest alibis for unsuccessful aviators. He claimed that he had mistakenly used cock's feathers in his wings. "Such had too much affinity for the dunghill", he said, "I should have used only eagles' feathers!"

As early as 1670, Geovani Alphonso Borelli demonstrated definitely that it was impossible to use a man's strength alone to achieve sustained and directed flight. It was a conclusion which had escaped the acuteness of all the other dreamers in the field. Now, the all important need for a power supply was at last recognized.

J. Bell Pettigrew, an English physiologist, studied intensively the wings and the motion of birds. Pettigrew added his theories to what has since been proved by high-speed photography. Birds use the feathers at the tips of their wings as rotors, twisting them with a propelling motion as they move up and down. He explained that birds fly simply by twisting their wings up and down once they are in motion, thus creating "elastic air screws". He recommended to the world at large what is essentially the design of the rotor blades of the modern helicopter, that is, two blades, tapering toward the tips, revolving rapidly under artificial power to force the machine upward.

However, even 70 years before this scholarly conclusion, Sir George Cayley had undertaken extensive investigation in this field. Taking his design from a Chinese top, he constructed miniature "helicopters" consisting of two large corks, a set of eight gulls' feathers, and a miniature bow on a spindle. The gull feathers were stuck into the corks at inclined angles and the cork was whirled by wrapping the bow string around the spindle. Cayley thus invented a gadget which could fly a dozen feet upward. He estimated that if the feathers could be elongated sufficiently to cover an area of 200 square feet and revolved with sufficient power, a man might be lifted. In the 1840's, Cayley constructed a helicopter using four 8-bladed rotors--a total of 32 blades. (Fig. 1-3) However, Cayley had discarded the steam engine as being too clumsy and weighty for aeronautical lifting. He suggested a device not unlike

today's reciprocating internal combustion engine as the proper mode of power, possibly using oil, gas or gun powder as a fuel. He made some unsuccessful experiments with powder and abandoned this idea.

Fig. 2-3 Cayley's Contraption

In 1842 in England, W.H. Phillips built a small model powered with a steam engine. Although the model weighed 20 lbs., it rose to great altitudes by using the engine to revolve the set of overhead fans. In the latter part of the last century, Thomas Edison in the United States experimented with models driven by an electric motor. He also experimented with an engine using gun powder for fuel but, understandably, abandoned the project after a serious explosion in his laboratory.

In 1863, George D. Landelle created a model which was a miniature "ship of the air" using pyramids of aerial screws. These were mounted on two masts which were topped by large parachutes which would open in emergency. The contraption rose ten feet off the ground before it collapsed. Shortly after, the American invented contra-rotation. This simply amounted to two propellers on the same axis revolving in different directions. It was the first time that the problem of torque had been considered. This model was demonstrated before the French Academy of Sciences and, at the time, created a growing public interest in Europe.

In the same year, Bishop Milton Wright, the father of Wilbur and Orville, picked up a helicopter top in France. He took it home and gave it to his sons. The object which their father had tossed into the air as a surprise was called by its now common French name, Hélicoptre, a name derived from the combination of Greek words, helix and ptero-rotary wing. The Wright brothers experimented with this toy, but became discouraged with it when they found that by enlarging its dimensions, it was unworkable without more power.

In the early part of the 1900's a Frenchman by the name of Breguet, who was to have considerable success in designing fixed wing airplanes during the coming World War I, built a full-scale machine lifted by four propellers, one for each point of the compass. A light aircraft engine was used as motor power. In August 1907 Breguet proved that a machine could be taken five feet aloft with the additional weight of a pilot for two

minutes. This "flight" did not prove much except that it did demonstrate that the Breguet model had a little more stability than its predecessors, a problem which was to plague all helicopter manufacturers. Breguet proceeded eventually to build three full-scale helicopters on much the same principles.

Another Frenchman, Paul Cornu, 1906, built a helicopter with rotors mounted on out-riggers and driven with a 24 h.p. engine. The machine rose into the air only a few times, never more than six feet. There seemed to be no way of obtaining simple stabilization beyond that height in a given time limit.

In 1909, an American father and son, Emile and Henry Berliner built a two-engine craft with contra-rotating rotors which succeeded in lifting a pilot untethered. They also developed an aircraft with side by side rotors over the wings. (Fig. 2-4) The machines achieved limited success in hovering and flying slowly forward.

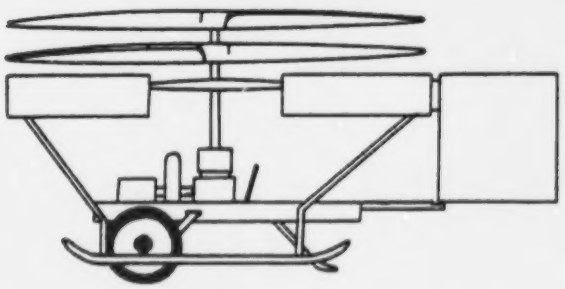


Fig. 2-4 Berliner Coaxial

In 1921, another American, De Bothezat built a large helicopter weighing 4000 pounds and consisting of four rotors carried at the ends of intersecting beams. Each rotor had six wide blades which turned very slowly, and control was achieved by blade pitch variation. De Bothezat even incorporated means to allow the machine to autorotate. However, this machine, again, was a limited success.

Probably the father of modern helicopters was Igor Sikorsky of the United States who had experimented with helicopters as early as 1907. In 1938, after achieving distinction as a designer of fixed wing aircraft, he again seriously attacked the problem of the helicopter. By 1941, he had produced the VS300 which embodied one main rotor and three auxiliary rotors on the tail of the machine. By mid 1941, Sikorsky had set a new endurance record by remaining aloft one hour and 32 minutes in his machine. From its initial configuration, the VS300 underwent a metamorpheasis and finally emerged as the well-known main and tail rotor configuration of today. Thus, Sikorsky had successfully constructed a relatively simple completely controllable helicopter. The VS300 developed rapidly into other single rotor production helicopters of which the Army and Navy bought many hundreds during the Second World War.

Partly because of the significant strategic purposes found for helicopters during the wars in Korea and Viet Nam, helicopters have progressively developed into the relatively efficient designs that are used today. The employment of turbine engines in modern helicopters has eliminated some of the problems of control which existed in the more archaic reciprocating types.

A little known fact is that Sikorsky was extremely reluctant to provide live demonstrations of his early experimental models, instead showing potential investors or customers motion picture films. Years later he would confess to the reason behind this: Apparently the early experimental models were extremely unstable and their behaviour in the air was almost comically erratic. Sikorsky therefore resorted to filming the flights and then showing the movies in slow motion. Erratic excursions in the flight then adopted the appearance of being purposeful smooth demonstrations of a helicopter's agility.

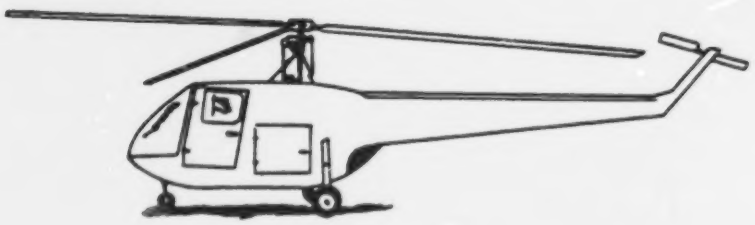


Fig. 2-5 Sikorsky S-52-1

The contributions of inventors, such as Cierva, in their development of autogyros cannot be ignored. The autogyros gave a number of essential ideas to the helicopter designers and showed that rotating wings could be used successfully for flight. Immediately after World War I in 1919, Cierva commenced his experiments. At first he did not envisage his craft as being much different from an airplane, witnessed by the fact that, in his models, he always retained the lower wing. His first model with contra-rotating rotors was unsuccessful. In 1921, he built the second model with a three-bladed rotor rigidly attached to the hub, but this was impossible to fly because of the gyroscopic action. In 1922, he had no more success with a redesigned five-bladed rotor attached the same way. The craft rolled over and crashed as it was about to take off. Cierva recognized the apparent fault: the lack of lift equalization.

In late 1922, Cierva built his fourth craft with a four-bladed rotor with hinged blades, allowing them almost total freedom of movement next to the hub, and allowing the natural forces of the air flow to compensate for the unevenness of lift. In January 1923, Cierva persuaded a friend pilot to fly this machine 200 yards off the ground. Two weeks later, the same craft flew 2 1/2 miles in three minutes and thirty seconds at about 100 feet off the ground. It showed amazing stability and could execute numerous manoeuvres at will. It rose steeply, flew slowly without apparent stalling speed barely moving in the sky, and landed without a run. In 1926, Cierva secured

financing from Britain and formed the Cierva Autogyro Company Limited. In 1928, he flew the English Channel by himself in his autogyro and toured 3000 miles across Europe in short hops.

In the same year, Harold Pitcairn secured rights to manufacture autogyros in Philadelphia. In France, a firm built autogyros and sold 40 to the French Air Force for reconnaissance purposes. The United States Army bought a sample and the Navy promptly bought three. One was landed with fanfare on the lawn of the White House for inspection of Herbert Hoover. Soon there were 90 autogyros built for flying in the United States. Three firms--Pitcairn, Kellett and Buhl were making them.

The Army Air Corps thoroughly evaluated this new type of aircraft. One of the first pilots, an Army Lieutenant named Gregory, after testing the machines for 100 hours, stated that autogyros were a definite step upward from balloon observation, but measurably below aircraft for observation purposes.

Fig. 2-6 Kellett VG-1B

The only use he could envisage for the autogyro was for training of personnel in the art of handling and maintaining the autogyro. However, what Gregory added was that the autogyro had given him the vision of a real helicopter.

Canadian history also contains some remarkable and little-known contributions to helicopter development. Canada, because of its great natural wilderness provides an ideal laboratory and setting to develop and improve helicopter design and operation.

In 1921, three brothers, Doug, Nicholas and Theodore Froebe moved from their birthplace in Chatsworth, Illinois with their parents to a farm near the sleepy rural Manitoba town of Homewood. Doug Froebe had, during the first war, seen many airplanes flying over their farm in Illinois and his interest had been aroused by them. As a boy he would fashion model airplanes out of whipple trees and shingles and any other materials he could find.

In 1927 the brothers built a Heath Parasol from a kit and attempted to learn how to fly it themselves. Unfortunately, it was somewhat underpowered and the boys were somewhat underexperienced and the machine fell prey to a barbed wire fence on the perimeter of their farm. This, along with another accident, stimulated them to start thinking about building a helicopter.

After having met with mixed reviews by several agencies (the principal of the Curtiss School of Aeronautics told Doug that vertical flight was impossible) the brothers, undaunted, proceeded to construct a helicopter. Parts were scavenged from various and sundry vehicles. For example, the rudder pedals were Model T Ford accelerators and the collective control was a Model T Ford tire jack. The engine, a Gypsy Sirus purchased in California for 100 dollars, was connected to a transmission constructed of crown gears and a pinion from a Chevrolet truck.

Contra-rotating rotors, one above the other, were employed as the brothers had realized at an early phase of development that torque was an important consideration. Collective pitch control via a handcrank changed the pitch of both the upper and lower rotors, while cyclic controls were connected only to the lower rotors. Directional control was achieved by control of torque, increasing pitch on the top and decreasing the bottom pitch by foot pedals.

Doug describes the first flight. "During the first attempt to fly the tail came off the ground about three feet. I hauled the stick clear back and the front wheels came off one at a time. We'd put the gas tank behind - half full of gas - and that helped to balance the aircraft, but it was a little nose heavy. Then we tried it again. We'd got off 5 feet and 50 feet forward three or four times. My younger brother thought he'd try it. He thought I wasn't trying hard enough. Well he got in it and tried it out and it so shook him up he couldn't try it a second time.

"It was a kind of a harrowing experience. The blades would make a resounding noise generated by the tip speed and the noise would bounce between the granary and the pool elevator. Everytime I hear a helicopter now, I can hear that kind of whistling bounce of the air coming from the tips. It still kind of shakes me up!"

Unfortunately, the machine was plagued by bearing failures and the boys gave up eventually. Both Nicholas and Theodore were killed in aircraft accidents, Nick in an Aeronca Champion while cropdusting, and Theodore in a Heath Parasol while performing aerobatics.

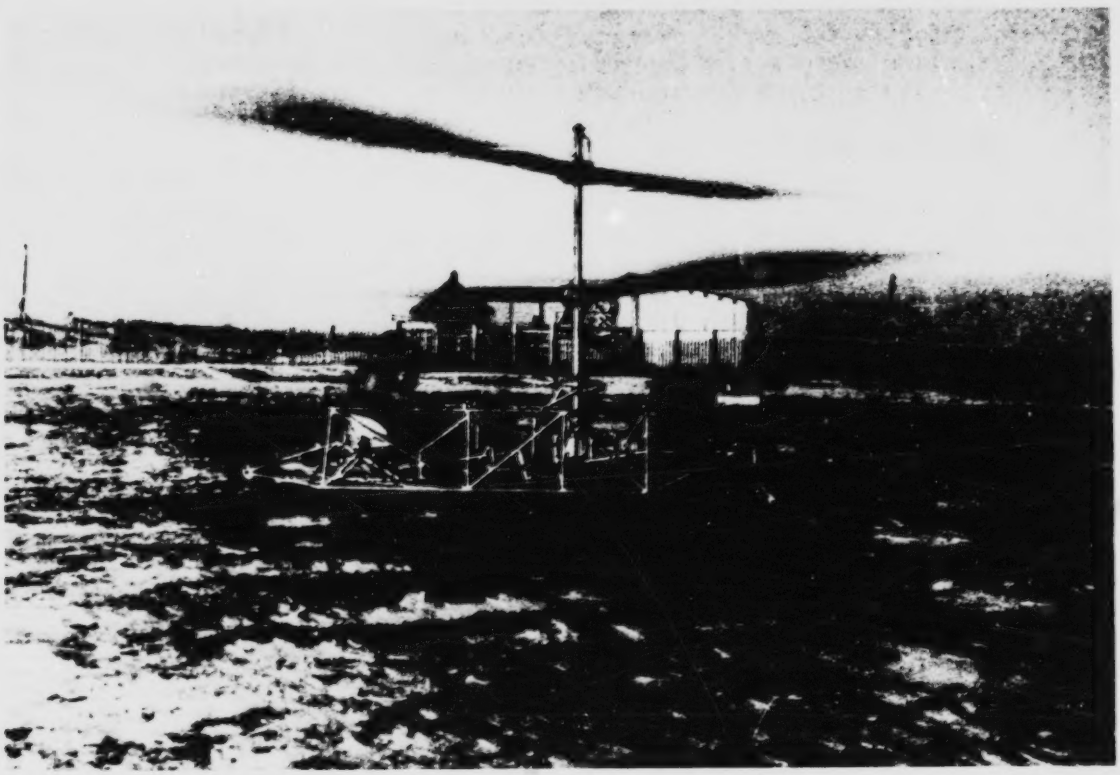


Photo 2-2

(Courtesy of Western Canada Aviation Museum)

The machine may be seen on display at the Western Canada Aviation Museum at 11 Lily Street in Winnipeg.

Jack Charleson of Ottawa was the only Canadian civilian helicopter pilot trained during the second war: he managed through several strokes of good fortune, to wangle a training spot on the Sikorsky R-4 which was the first mass-produced helicopter. Graduating from the course on July 31, 1945 having flown 17 hours and 10 minutes, he became Canada's first trained civilian helicopter pilot.

Following the war there was a paucity of flying jobs compared to the number of pilots returning home from wartime service. A few turned to helicopters as a possible source of employment and trained at the Bell Training Center in Buffalo. Among the first were Al Soutar, Tommy Noakes, Paul Ostrander, Jimmy Sampson and Sten Lindberg, who ferried the first Canadian registered Bell, CF-FJA, a 47B-3 to Toronto in March 1947.

Paul Ostrander had Canada's first recorded helicopter accident in CF-FQR near Red Lake, Ontario, while making an emergency autorotation in June 1947. Jimmy Sampson went down in CF-FQS a month later after hitting a telephone pole while cropdusting in Manitoba.

Another bush pilot on the West Coast was attracted by the potential the helicopter might have in agricultural operations. This was Carl Agar who, with CF-FZX, founded in 1947 one of the largest helicopter services in the world, Okanagan Helicopters Ltd. CF-FZX unfortunately was damaged when it hit a powerline just a month after being imported.

Carl Agar, confronted with some contracts involving transporting surveyors in the mountains, performed some of the early experiments in mountain flying, efforts which were to win for him the 1950 McKee Trophy. Bud Tillotson later perfected various mountain flying techniques and became one of the world's leading authorities on helicopter mountain flying.

Okanagan Air Services was contracted to work in the Kitimat-Kemano hydro development where Alcan was building its aluminum refining complex. Because of the air support required, Agar purchased Canada's first S-55, then considered to be a heavy lift helicopter.

The Department of Transport was attracted to the helicopter for support of ships in northern operations and in 1950 modified the after deck of the icebreaker CD Howe into a helipad and set sail with an S-51 strapped to the pad. Despite an accident involving loss of the helicopter and a passenger due to a failure to remove all of the tiedowns prior to liftoff, the DOT was impressed with helicopters and acquired a Bell 47 for further tests. Today the Canadian Coast Guard operates a large fleet of helicopters, thanks to these pioneering efforts.

Canada in 1946-47 almost got into the helicopter manufacturing business. Bernard W. Sznycer, a Polish aeronautical engineer, designed a helicopter and built a prototype which was first flown in 1947. The machine, an SG-V1-C, a small three seater was described as being an excellent machine by the test pilot, Henry J. Eagle Jr. Christened the Grey Gull, the helicopter was put through a rigid flight test program and became the first helicopter to be certified in the British Commonwealth. Ironically, just as plans were being finalized to mass produce the machine, Sznycer's financial backers pulled out and the Grey Gull was "goosed".

In reviewing the history of helicopter development, it becomes immediately obvious that they did not receive the same degree of attention as their fixed-wing counterparts, the design often taking place in a sort of "back room" atmosphere. In addition, it is apparent that the design of helicopters followed fixed-wing design by a number of years, and when studying the modern helicopter it is obvious that many

fixed-wing principles have been applied. Perhaps because they are not so commonplace, or, possibly because of their utilitarian nature, helicopters do not enjoy the status and the glamour of the higher, faster, sleeker jet aircraft. Thus it appears that the man in the street of aviation, as well as those in the field of aviation medicine have become so enamoured with fixed wing flying that many of the "grassroots" problems of rotary-wing flying remain unravelled. It is high time that the helicopter be no longer viewed as an aerial truck with a propeller on its top, but rather be recognized as a distinct entity, quite apart from the fixed-wing airplane! Dedicated pilots and crews are aware of this understudy position, as well as the specialized flying skills required in handling this unique form of aircraft.

We must realize that the helicopter pilot is faced with distinct problems as he summons forth his almost infinite skills and patience to guide this complex machine. One has only to look at the accident rate of helicopters as compared to fixed-wing machines to see that there exist many serious problems and that a great deal of work remains to be done in this unique area of aviation. Rotary-wing flight presents a new perspective in flying and therefore the prevailing problems must be defined more clearly; the solutions must be resolved, and the industry so informed in order that helicopters can be more safely utilized, and their maximum efficiency realized by both the machines and the pilots. This is particularly true in countries such as our own, Canada, where development and exploration of the North depends so much on aviation; where helicopters are being used to explore, map, and supply these vast, remote, barren areas.

CHAPTER III

BASIC AERODYNAMICS

By Hugo Leech

In our expanded concept of Aviation Medicine, we have come to view the pilot and the airplane not as two separate entities but as a man/machine complex, both being integrated into an inter-dependent mechanism. A direct communication exists at the man/machine interface to which much of the effort of human factors investigation has been dedicated. In order to understand the human factors applicable to rotary wing flight, it therefore becomes essential that we have a working understanding of the helicopter and how it flies.

The wings of all aircraft are designed to one fundamental principle. When driven through the air, a pressure differential is set up as a result of the air speeding up over an aerofoil and remaining at a constant velocity below it. Since velocity and pressure are inversely proportional, an upward force-lift is created, which when it overcomes the weight of the aircraft, will result in flight.

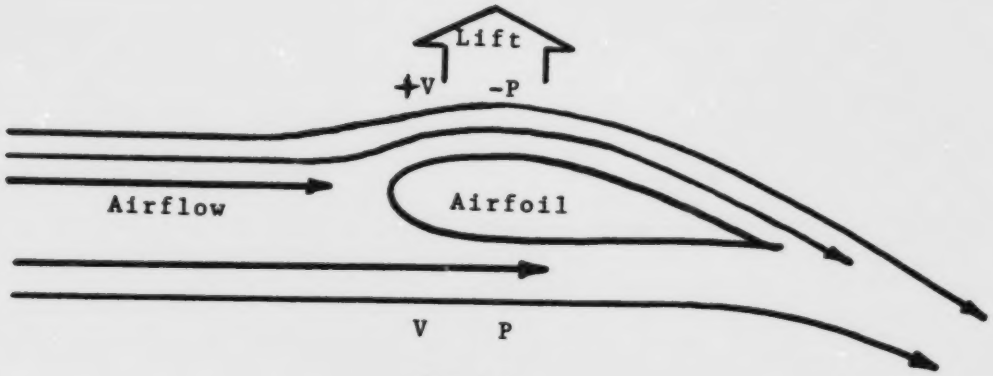


Fig. 3-1

Lift is affected by the angle at which the aerofoil meets the airflow, the density of the air, the size and shape of the aerofoil, and the velocity at which it is propelled.

The aerofoils of an airplane, the wings, are bolted on at a fixed angle of incidence which means that the whole aircraft has to rush down a runway before flight can take place and is obliged to keep moving forward to avoid the Wright Brothers' "falling with deathly violence". The aerofoils of a helicopter produce lift as a result of being rotated. Furthermore, the angle at which they meet the airflow can be altered by the pilot. As a result the helicopter does not need a take-off run, but can rise vertically from the ground, hover motionless and move sideways and backwards.

This, of course, is an enormous advantage, particularly where there is a lack of suitable room on the ground for a runway. As you will see in the next few pages, this capability is very dearly bought. Aerodynamically and mechanically, the helicopter is hideously complex. In fact, many airplane pilots will tell you that the helicopter is like the bumble bee, an aerodynamic impossibility.

HOVERING FLIGHT

Photo 3-1

A typical flight of a helicopter will give you some idea of the complexities facing the designer. The problems start as soon as the pilot starts the engine and the rotors begin to turn. The tip of a rotor blade is obliged to travel faster than the root. Since velocity is a component of lift, a greater upward force is exerted in the tip than at the root. Unless the designer tapers the blade or progressively reduces the basic angle at which it meets the air, unacceptable bending forces will result.

Fig. 3-2

As the blades speed up, centrifugal force increases and it is interesting to note that whereas lift, thrust, weight and drag are measured in pounds, centrifugal force tends to be regarded in tons. Although meaning fairly massive attachment points at the hub, this same force is vital to safe flight. Helicopter blades are not able to support the weight of the aircraft unless they are rotating and kept rigid by centrifugal force.

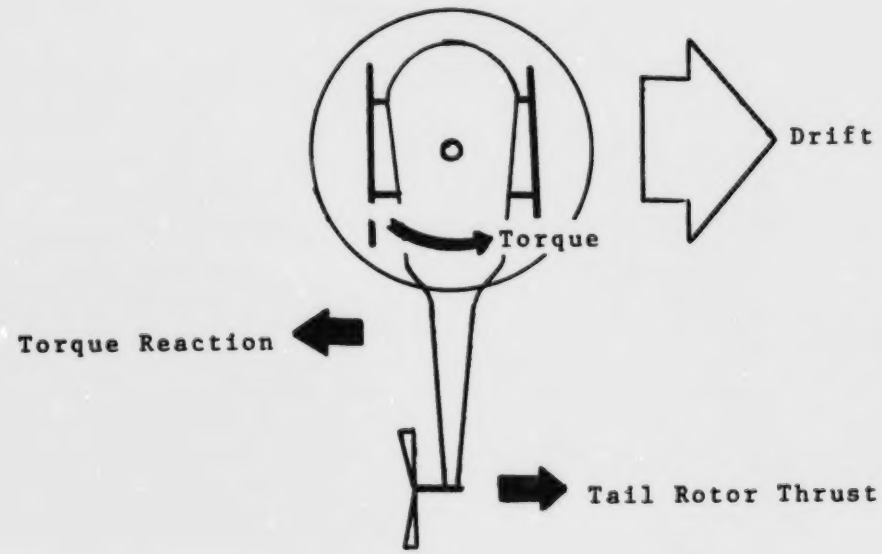


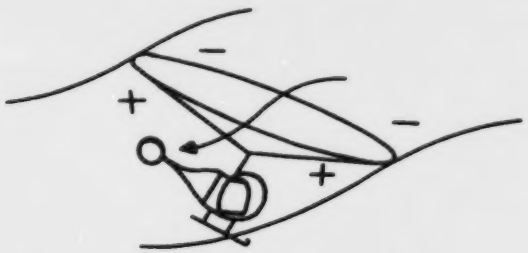
Fig. 3-3

If the helicopter is sitting on water or icy ground, another problem will manifest itself on startup. The rotating blades produce torque. Unless the designer takes care to overcome this, the helicopter will rotate at an equal velocity in the opposite direction. If the helicopter is sitting on firm ground, this phenomenon will not manifest itself until the helicopter becomes airborne.

There are several ways that the designer can overcome the problems of harnessing torque and torque reaction. By far the most common is the addition of a tail rotor which provides thrust in the opposite direction. Like centrifugal force, this is used to advantage by the designer. By giving the pilot authority over the amount of thrust the tail rotor delivers, the heading of the helicopter can be controlled.

This is only a partial solution. Torque and its reaction are a couple. Since the tail rotor constitutes a moment, a residual force results which will drift the whole aircraft sideways unless some provision is made to prevent this. The designer will either rig the controls in such a way that this drifting force is largely overcome, or will leave it to the pilot to take care of, as the need arises.

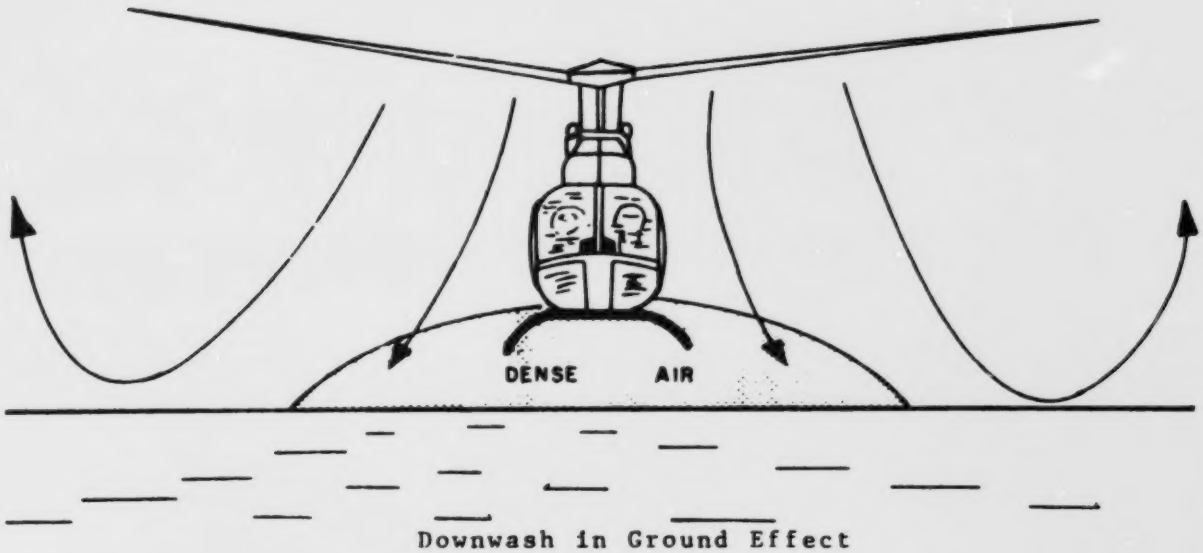
You can see from Fig. 4 that the air passing over the rotor blade is displaced downwards to some extent, a number of blades rotating at high RPM creating "downwash". In forward flight or in a strong wind, this downwash escapes from under the rotor disc, but at a low hover it gets blocked somewhat by the ground below. This effectively reduces the velocity of the airflow passing into the rotor



Downwash in Forward Flight

Fig. 3-4

disc from above and it is an interesting fact that a reduction of this kind increases the lift produced. Hover-in-Ground Effect therefore requires less power than Hover-Out-of-Ground Effect. It also requires more effort from the pilot to control the helicopter accurately because the helicopter tends to be very unstable in this mode.



Downwash in Ground Effect

Fig. 3-5

FLIGHT CONTROLS

Before taking this flight any further, it might be a good idea to describe the flight controls in a helicopter. The Cyclic controls the aircraft in the rolling and pitching axes and is used to climb, descend and to change heading in cruising flight. It achieves these effects by changing the pitch angle on each blade cyclically, thus tilting the rotor disc in the desired direction. Because the rotor disc has some of the properties of a gyroscope, the designer is obliged to rig the controls to overcome a 90 precession or Phase Lag. The Cyclic is held in the right hand and is extremely sensitive, needing only small wrist movements to produce large responses from the helicopter. Pilots are taught to keep one hand on the Cyclic at all times and this is the main reason that the captain of a helicopter sits in the right seat, whereas the traditional captain's seat in airplanes is on the left. Sitting on the right side leaves the left hand free for ancillary controls, radios, etc.

Controlled by the left hand too, is the Collective. Raising this control increases the pitch angle and all blades collectively and will cause the helicopter to ascend. Lowering it will cause a descent. Provided the controls are rigged properly, this control is less sensitive than the Cyclic.

In most types of helicopters, the Collective has a twist grip throttle incorporated. Raising the Collective results in more lift being generated by the rotor blades. This leads to an increase in drag which must be overcome by an increase in power from the engine. In more modern machines, and particularly those with turbine engines, these changes in power required are taken care of automatically by a governer in the

fuel system, but in older types, the pilot has to alter the power setting every time he raises or lowers the Collective. He works in a very narrow RPM band on the tachometer. Exceeding the manufacturer's limits will lead to severe strain on the rotor system, due to the resulting excess of centrifugal force. Dropping below the limits will result in the centrifugal force being insufficient to keep the blades adequately rigid, and will lead to a reduction in the effective size of the rotor disc.

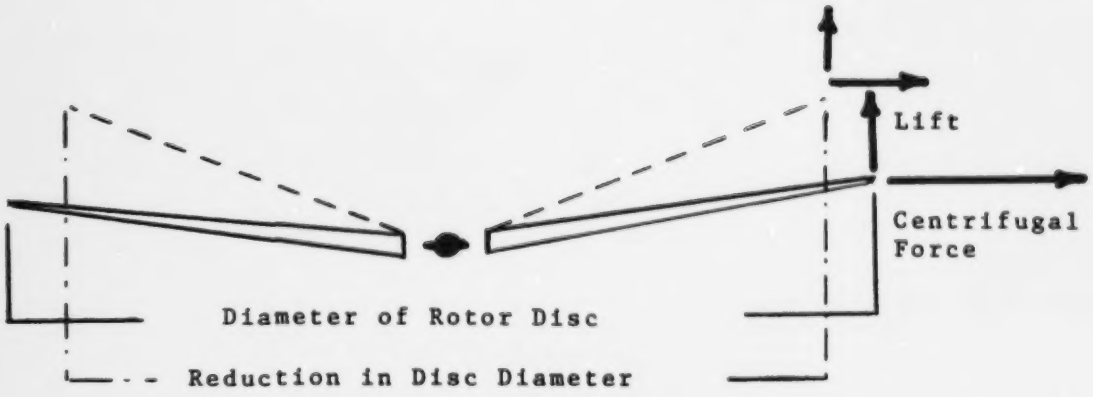


Fig. 3-6

Tail Rotor Pedals complete the control layout. They change the pitch on the tail rotor blades and are used to control the heading of the helicopter in hovering flight, and to maintain balanced flight at the cruise. Any movement of the Collective made by the pilot necessitates a complementary movement of the pedals, to prevent the helicopter yawing.

FORWARD FLIGHT

Photo 3-2

To move the helicopter from the hover into forward flight the pilot eases the Cyclic forward. Three things will then happen more or less simultaneously - Dissymmetry of Lift, Loss of Ground Effect, and Translational Lift.

Dissymmetry of Lift is the term used to describe the phenomenon whereby the advancing blade (a rotor blade moving in the same direction as the helicopter, (see Fig. 3-7) produces more lift than the retreating blade.

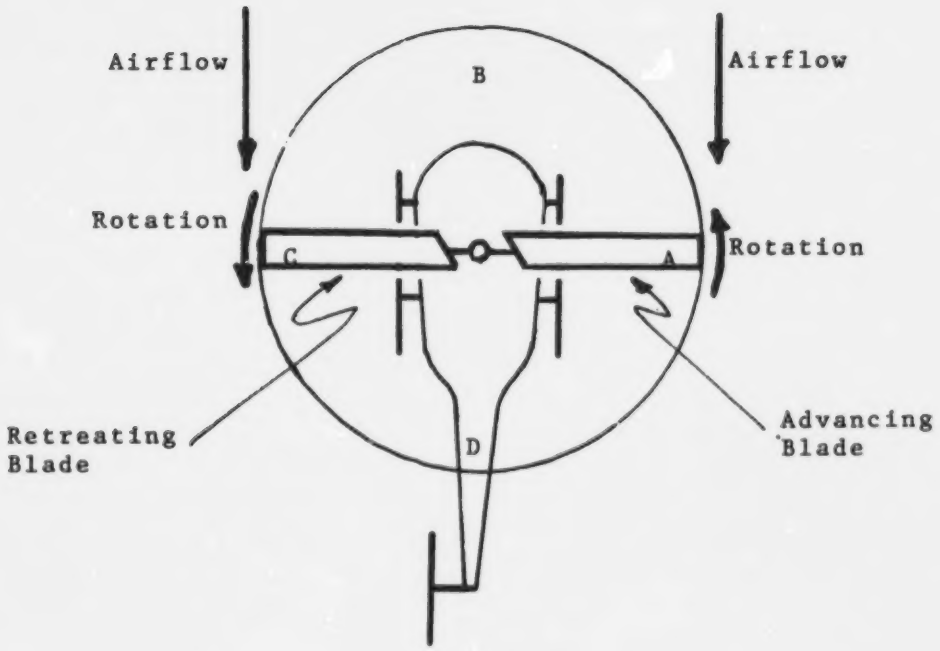


Fig. 3-7

From Point D in the diagram, to Point B, the rotational velocity of the blade opposes the airflow velocity and must therefore be added to it. From Point B to Point D the converse effect takes place. The most common method of overcoming this difference in velocity and therefore lift, is the provision of flapping hinges. These work in the vertical plane at the hub and allow the advancing blade to "give" with the increased airflow, or "beat down" into the decreased airflow on the retreating side. Dissymmetry of lift is thus effectively overcome, although the pilot has to overcome Flapback, the term used to describe the tendency of the whole rotor disc to flap up at the front and flap down at the back of the helicopter.

This capability for the blades to flap, can itself prove a liability, particularly when the helicopter is equipped with more than two rotor blades. The flapping motion tends to move the centre of mass of a blade relative to its axis of rotation, and this will result in the blade wanting to speed up or slow down in relation to the other blades. Severe vibration will result unless the designer makes provision for some limited movement in the horizontal plane. A dragging hinge is therefore incorporated, together with dampers which prevent the movement from becoming excessive.

Although the fitting of drag hinges will cove the adverse effects of flapping, their installation can produce problems of their own. Ground Resonance is the name given to a sympathetic vibration that can set up when the helicopter is resting on its

landing gear, and only aircraft with drag hinges are really prone to it. It can occur when the dampers on the rotor head, or those fitted to the landing gear, are not set up precisely in accordance with the manufacturer's specifications. Some helicopters will even get ground resonance when they are properly set up. These vibrations can build up at an alarming speed and can lead to the helicopter rolling over and thrashing itself to total destruction within seconds.

What with flapping hinges, drag hinges, dampers, static and dynamic stops to prevent excessive flapping, and pitch change mechanisms, the rotor head can be a massive and extremely complex affair. In recent years, the development of epoxies, fibre glass and metals with long fatigue life, have given the designer opportunities to produce rotor systems that are far simpler mechanically.

As the helicopter moves forward, it will leave ground effect. This is in nil wind conditions. (In a strong wind, there will be no ground effect to start with.) The helicopter will now tend to sink back to the ground. This tendency is compounded by the pilot's initial movement of the cyclic, which has the effect of converting some of the vertical lift into horizontal thrust. To overcome this sink, the pilot must increase power with the collective, and correct for the resultant yaw with the pedals.

At about 12-15 MPH, the helicopter will acquire Translational Lift. Forward speed leads to an overall decrease in the air flowing through the disc, and, as described earlier, this increases the effective lift of the rotors.

DYNAMIC ROLLOVER

An aerodynamic problem that manifests itself with distressing frequency in helicopter operations is Dynamic Rollover. If a helicopter is parked untethered on the rolling deck of a ship it can obviously tip over on to its side. This would be a case of static rollover. Dynamic rollover occurs when the pilot is taking off, and occurs at far less an angle than static rollover. It is necessary for one skid to get snagged by a ground obstacle such as a tree stump or rock. One skid stuck in ice will produce the same effect. The natural reaction of the pilot on finding the helicopter rolling to one side is to attempt to level the aircraft with cyclic and to raise the collective in order to free the aircraft and get airborne. This is a fatal mistake. The rate of roll increases because the lift produced by the rotor disc has become inclined and converted into thrust. This is happening at a point way above the centre of gravity, and a rate of roll is rapidly incurred which is impossible to overcome even with full opposite cyclic.

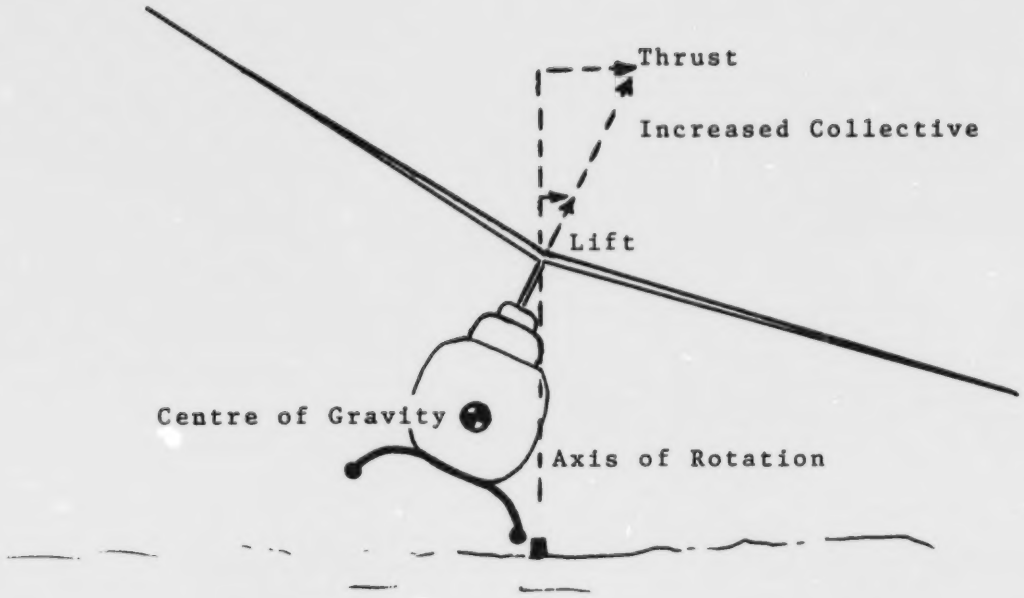


Fig. 3-8

VORTEX RING STATE

In the process of producing lift, all aerofoils leave a turbulent wake behind them. This disturbed air is generally in the form of vortices forming at the tip of the wing or rotor blade. The airplane necessarily leaves this turbulence behind, and poses a threat only to other aircraft that fly too close behind it. Due to its greater manoeuvrability, the helicopter can get into its own wake turbulence. This is called Vortex Ring State. It is not a common occurrence, but it can happen if the pilot causes his machine to descend at a fairly high rate with little or no forward speed.

The results are dramatic. The turbulent air plays havoc with the lift and thrust of the rotor system and leaves the pilot with little or no control of his aircraft. The already high rate of descent is further magnified and cannot be arrested with the

natural use of the collective. Several hundred feet of airspace are needed to recover from this unnerving situation, and since it is most likely to occur during an approach for landing, this airspace is often not available.

AUTOROTATION

A very common misconception, shared by the Wright Brothers themselves, is that the helicopter is doomed if the engine fails. Laymen will describe (with morbid glee) how it will tumble end over end to certain destruction. The truth is quite different. In fact, the helicopter is totally manoeuvrable and controllable following engine failure, and has the advantage over the airplane in that it needs only an area the size of a tennis court on which to land safely.

There is no denying that the pilot has to react quite swiftly to an emergency of this kind. The drag which is being produced by the lift from the blades is overcome by power from the engine. Without the engine, the drag will very quickly slow the blades down to where they can no longer support the aircraft. The pilot, therefore, has to get rid of this drag in very short order. This he does by lowering the collective, and he has only one or two seconds to do this before RPM decay becomes irrecoverable.

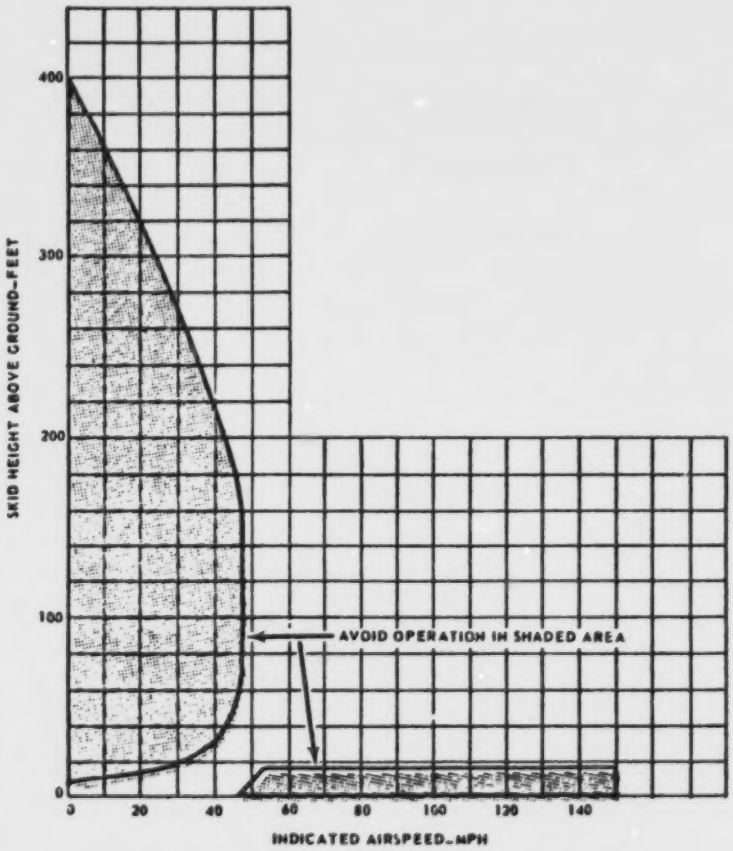
The resulting descent is called Autorotation. This is not merely the inertia of the blades providing lift until they have slowed down. The rate of descent that results from the pilot lowering the collective actually drives the blades round and the helicopter can autorotate for as long as necessary. One recorded autorotation started at over 30 000 feet and took 15 minutes to complete.

Following an engine failure and entering autorotation, the pilot is able to turn into wind and select a safe place to land. The glide ratio will be in the order of 1:4 and the rate of descent 1500-2000 feet per minute. From the low altitudes at which helicopters are generally operated, this means that the machine is on the ground in quite short order.

As the helicopter approaches about 100 feet above ground in autorotation, the pilot raises the nose in a flare that will reduce his forward speed, which up to this time will have been in the 45-70 MPH range, and will reduce his rate of descent. At about 10 feet he can raise the collective just once, which will give him short-term lift that is sufficient to cushion the landing. A landing run of 25 feet is generally all that is required and in optimum conditions, the helicopter can be landed very gently with no forward speed at all.

Despite this capability, there are areas in the flight envelope where the chances of a safe landing following an engine failure are slight. All helicopter flight manuals contain a Height Velocity Chart which shows where these areas are. It is known colloquially as the Dead Man's Curve. The prudent pilot will take care to avoid the shaded areas if at all possible.

HEIGHT VELOCITY DIAGRAM



Height Velocity Diagram

Fig. 3-9

Autorotations are demanding, precision manoeuvres requiring a high degree of skill and judgment. This can only be acquired with extensive training, and retained with practice. A problem of autorotational training is that whereas the prime purpose of a real emergency power-off landing is to save lives, at the expense of the helicopter if necessary, practice forced landings have to be good enough to avoid damaging the aircraft.

MAXIMUM SPEED LIMITATIONS

It is a well-known fact that if an airplane pilot attempts to fly too slowly, the aircraft will stall. The airflow over the top of the wing will suddenly become turbulent and will exert a downward force instead of lift. The result is a very rapid loss of height and if the airplane is close to the ground to start with, an accident occurs. The helicopter can also get into a stall situation, but unlike the airplane, this is a function of going too fast rather than too slowly.

At very high speeds the relative airflow over the rotor disc can get dangerously close to the rotational velocity of the blade on the retreating side. This blade will flap down in attempt to compensate for this apparent drop in airflow velocity and in doing so, can stall. The results of this happening vary according to which pilot you talk to or which books you read. Whereas there is unanimous agreement that the nose of the helicopter will rise sharply, expert opinion varies on whether the aircraft will roll to the left or right. The truth is probably that it could do either.

In order to get this Retreating Blade Tip Stall, the pilot must work hard at exceeding the manufacturer's maximum speed limitations and ignore the heavy vibrations that will undoubtedly precede the stall itself.

Whereas the retreating blade/tip has a low airspeed in these conditions, the advancing blade will be approaching the speed of sound or "sound barrier". The pressure of the air ahead of the blade will build up and lead to buffeting and ultimately to compressibility stall. The result of these problems and others associated with them is that the maximum speed of conventional helicopters is less than 200 MPH and would appear likely to remain so far into the foreseeable future.

STABILITY

Stability is generally regarded under two headings, static and dynamic. Static stability is when an object returns to a datum having first been disturbed from it. A frequently-used example of static stability is the pea sitting in the bottom of a semi-circular bowl. If the bowl is moved, the pea will move away from its resting place but will return to it when the movement stops. If the pea was resting on top of the inverted bowl, which was then moved, it would not return to its original position and would be considered to be statically unstable.

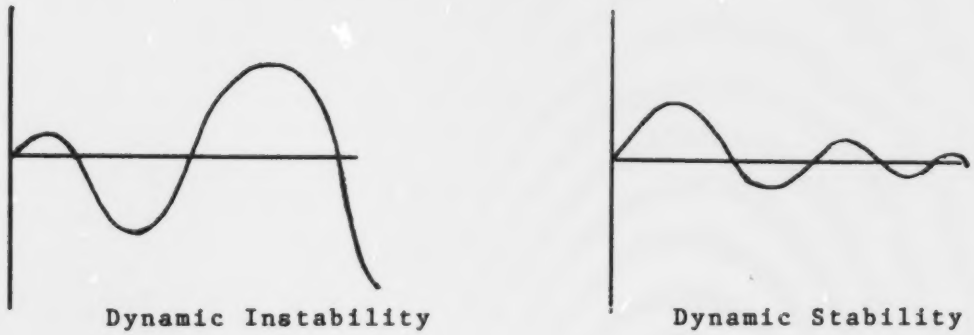
Static Stability

Static Instability

Fig. 3-10

Dynamic stability refers to objects that are statically stable to start with, and describes their behaviour when returning to the datum. An object that is statically unstable is not considered to have any dynamic stability at all.

When an object, on returning to the original datum, does so in ever decreasing oscillations, it is said to be dynamically stable. If the oscillations increase, it is dynamically unstable.



Dynamic Instability

Dynamic Stability

Fig. 3-11

A helicopter's stability has to be considered in three axes-roll, pitch and yaw, and in at least two phases of flight-hovering and forward flight. It fails to show up well in most of them. In hovering flight, in nil wind conditions, the helicopter tends to be statically unstable. In forward flight, it is dynamically stable in the yaw plane, dynamically unstable in pitch and statically unstable in roll. This, together with the sensitivity of the controls, results in a machine that would probably be quite unacceptable in all other fields of mechanical endeavour. Some manufacturers have made the attempt to ease the pilot's lot with stability augmentation systems (SAS). Bell were quite successful with the stabiliser bar which they introduced in the 1950's.

This was a bar with weights on each end, which rotated with the main rotor blades and acted like a gyroscope. Its rigidity in space damped down the random movements of the rotor disc that came from turbulence and gusts, and resulted in an aircraft that was easier to fly than many of its contempories.

More recent stabilization systems are electronic and can be coupled with automatic pilot systems which will allow hands-off flying in cruising flight. Systems of this type are extremely sophisticated and expensive, but are vital in operations where sustained flight under instrument flight is contemplated.

Two other areas inhibit flying helicopters in clouds, the lack of specifically designed instruments, and icing. All the instruments and radio aids used in helicopters were designed with the airplane in mind. The result is that although the helicopter can perform quite adequately, it has to maintain positive airspeed for the instruments to provide reliable and useful information to the pilot. Much of the helicopter's versatility is therefore lost.

Airframe icing has so far proved to be an insurmountable obstacle to unrestricted flying in cloud. It is caused by supercooled water droplets that can occur over a wide range of cloud and temperature conditions. It can also occur beneath the cloud base in the form of freezing rain.

Ice not only can add a critical amount of weight to the aircraft but can freeze control lines, rotor heads and any other moving part. It takes very little ice to form on the rotor blades before sufficient autorotative performance is lost. This means that if the engine quits, the helicopter really <u>will</u> tumble out of the sky. Centrifugal force will often prevent a serious build-up of ice on the blades, but this shedding in itself can be a hazard. Unequal shedding of ice can give the pilot severe control problems and at the very least, massive vibrations that will ruin his peace of mind. Chunks of ice thrown from rotor systems are also somewhat dangerous to ground personnel.

This then, is a brief outline of the complexities of the helicopter. Every effort has been made to avoid the use of esoteric jargon, but despite this, one or two definitions may assist the reader. These are:

a) <u>Transition</u> - Strictly defined as a change of direction or velocity in any direction, but more commonly used to describe the process of proceeding to the hover from forward flight and vice versa.

b) <u>Translation</u> - The horizontal movement of a helicopter through the air.

c) <u>Touch Down Autorotation</u> - The engine of the helicopter is nearly always left running during a practice autorotation. True simulation of the real thing is ensured by the presence in the transmission of a free wheel unit. It is therefore possible to re-synchronize the rotors and engine at any time during the descent, and revert to normal powered flight. A touchdown autorotation is one where the exercise is continued until contact is made with the ground.

d) P.F.L. - Practice Forced Landing. This is an unscheduled landing made as a result of a simulated emergency.

For those readers whose imagination has been fired by the complexities of rotary winged flight, there are several books which explain the details in far more detail than has been possible here. Among them are, The Helicopter And How It Flies, by John Fay, and The Dynamics of Helicopter Flight, by the late George H. Saunders.

CHAPTER IV

THE MAN

"In studying the relationship between man and the machines he creates one comes to learn more about man. Nowhere is this relationship more critical than in aviation".

In Chapter I it was mentioned that the success of a flight depends upon three elements: the man, the machine, and the environment, comprising the aerospace system. In order to understand how one operates it is necessary to understand all three. We have now had a basic look at the machine (and some of the men who created it) and now it is time to have a closer look at the human element.

In any man machine system a human operator is placed in the loop in such a way that he is used as a processor of information. Information is displayed to him via instruments and other audio, visual and tactile cues and once decisions have been made based on this information man takes action in the form of manipulating controls or other appropriate responses. The degree of man's involvement in the system depends upon the complexity of the task and other considerations. Although machines are sometimes at an advantage in relation to human performance, man has one overriding advantage and that is the fact that he is able to make decisions resulting from judgments based upon what might be inadequate information in machine terms. For example, a computer cannot arrive at a conclusion without having been fed all pertinent information and having been given the exact method of arriving at the conclusion. Man was not meant to be purely a passenger; he must be given the capability of providing some input if the overall system is to succeed in all circumstances.

In the flying environment man has four basic tasks:

1. The identification of the goal of the craft.

2. The recognition and measurement of the machine's current position in relation to the goal.

3. The selection of a path to the goal consistent with vehicle restraint.

4. The selection and use of sensing and control mechanisms to physically realize the required path to the goal.

Five aspects of skilled response which are relevant to the flight task are:

1. Cognitive skill - the ability to understand the nature and function of both task and equipment.

2. Perceptual skill - the ability to identify relevant information and handle inputs from multiple sources.

3. Coordination - the ability to integrate responses with respect to both one another and time.

4. Memory - the ability to retain information relating to performance, procedures, tasks, etc.

5. The ability to exercise the above skills under conditions where stresses such as speed and danger are present.

In addition, certain social skills are important in order for proper crew functioning.

Therefore, it becomes obvious that in order to achieve these goals and exercise these skills, several events in terms of information processing must occur:

1. The man must be presented with information in a fashion which allows him to perceive it.

2. The man must be capable of receiving this information, i.e., his receptors must be functioning properly.

3. The man must be capable of priorizing the information which he receives.

4. The man must be capable of arriving at a rational and pertinent decision based on the information which he selects.

5. He must be capable of reacting to the decision in a coordinated, appropriate fashion.

Not so simple, is it? Well, it is possible to understand the process if one examines the various steps in information processing individually. One of the models of information processing which aids in understanding the complex process is the Broadbent model which is a schematic similar to an avionics system flow diagram:

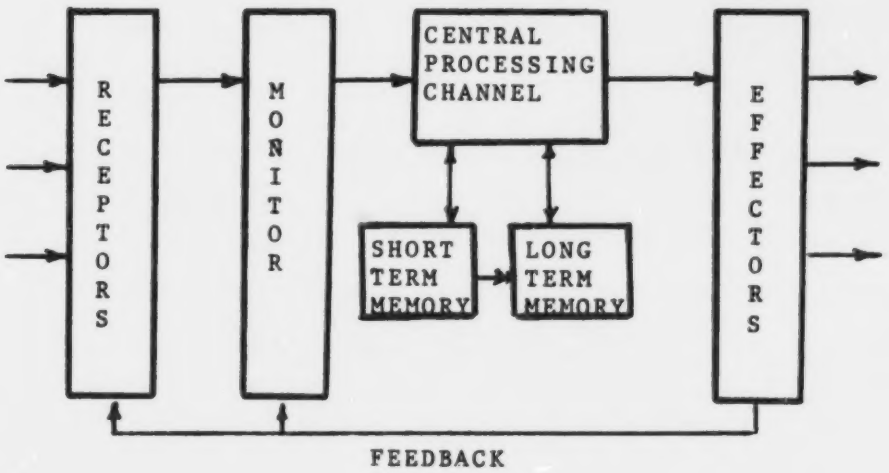


Fig. 4-1

RECEPTORS

Receptors of information or the perceptual mechanisms consist of the various senses, the two most used in the aviation environment being vision and hearing, provided that adequate cues are present. Even though a pilot relies to a great extent on his vision, the information he is capable of gathering is often inadequate for an aviation environment, or may be misleading.

The eye is capable of perceiving a very narrow band of radiation, a band which we call "light". Other creatures are capable of perceiving a much wider band, for example, ultraviolet light in certain insects and electromagnetic flux in certain migratory birds.

Although most pilots consider themselves to be eagle-eyed this is far from the truth. A pilot's area of sharp vision is very small - an area of about the size of a quarter at four feet - as a result of the relatively small fovea with which we humans are equipped. At a mere five degrees away from the foveal axis vision drops off to about one quarter of the central vision and at twenty degrees it is one twentieth. Therefore, the peripheral retina, which is also not sensitive to colour, is really like a radar screen. It may, through motion contrast or brightness contrast, indicate that an object is present and the fovea is then directed to identify the object.

Studies have been done to demonstrate this problem in the aviation environment, for example, the "see and be seen" studies in the U.S. It was found that under ideal visual conditions a pilot with good vision would be able to pick up another aircraft at seven miles. If the aircraft was 45 degrees out of the line of vision this was reduced to 2 1/2 miles and at 60 degrees 1/2 mile - far too close in view of modern closing speeds. An additional complication is the fact that when two vehicles are on a collision course there is no motion contrast.

In clear blue sky conditions a phenomenon called empty field myopia occurs. Unless the eye has some point to fix upon the accommodation randomly cycles back and forth from the near point of vision to infinity. All pilots can recall peering out of the windscreen looking for an object in a clear blue sky, suddenly spotting an object only to realise that they are focused on a speck of dirt or a scratch on the windscreen.

For the above reasons scanning techniques are taught to the airman, or should be. He learns to scan his fields of vision and to maintain infinity focusing by occasionally glancing at a distant cloud or object on the ground.

Riordan and other investigators have determined that there are different neurological pathways for peripheral vision as compared to central. Orientation cues are more powerful in peripheral vision than in central. This can easily be demonstrated by performing the following experiment:

First, stand up. (Your seat of the pants cues were probably numbed by now anyway.) Cover one eye with your hand and make a fist with the other, holding it in front of the uncovered eye so that the central vision is obstructed but you have a circle of peripheral vision. Now stand on one foot. Easy isn't it. Now repeat the process but instead of putting a fist in front of the good eye make a circle, pinhole sized, with your forefinger and thumb in front of the "good" eye so that only central vision is

available and peripheral vision is obstructed. It becomes more difficult to stand on one foot.

So what have we done in terms of human engineering for IFR flying? We have designed a small artificial horizon which uses only central vision, the weaker in terms of orientation! Malcolm in Canada has designed an artificial horizon which consists of a projected light bar across the instrument panel - an apparently logical solution.

What of other creatures with whom we share the aviation environment? Birds not only have side mounted eyes giving them much larger fields of vision, but there are some basic differences in ocular structure. For example, our accommodation is controlled by smooth muscle which is relatively slowly reacting, whereas the sauropsid (bird's) eye is controlled by striated which is lightning fast.

More important is the size of the fovea. Birds of prey have very large fovea which allow them to spot small animals from great heights. Sea birds have wide fovea allowing them sharp vision around the entire horizon.

It is now obvious that we, in many ways, are perhaps not suitably equipped to function as well as other aviation creatures. Even our vision, which is our most important sense, is inadequate compared to a bird's vision, and we can therefore conclude that the quality of information perceived is at best, marginal.

MONITOR

Each instant we are being constantly bombarded by what would be an overwhelming amount of sensory information. While you are reading this there are other peripheral visual inputs (concentration tends to remove these) and there are various sounds such as the rumble of a fan or the sound of a car and even a sensation of mild discomfort arising from your left big toe.

However, the amount of information man is able to process is limited, and therefore wanted or needed information must be filtered from that which is extraneous or not needed. Such is the function of the monitoring system which is programed by learning, experience and perhaps to some extent heredity to reject information. An example of how this works occurs every time a pilot flies. One of the first things he does is to program his monitor with the aircraft's registration letters. While flying he may be apparently ignoring ATC communications with other aircraft, but if a controller calls out his registration he responds as if by magic - his monitor has been scanning sensory inputs and has alerted him to priority information. Part of learning to perform a complex task such as flying consists of programing the monitoring system with priority information.

Once information has been selected, it is passed on to the central processor.

CENTRAL PROCESSOR

Information which arrives at the central processor is that information which is required to be remembered or on which a change in behaviour is to be made, for example, avoidance action.

One of the limitations of human information processing is that decisions can be made only upon one item of information at a time - it is thus a single channel system. Therefore, rate of information processing becomes important.

One may make the observation that it is possible to perform more than one action at a time, for example, drive a car and carry on a conversation. What is happening in this case is that attention is being rapidly shifted, and through learning to drive the car a new system of priorities has been devised - the monitor is still scanning the environment as would be evidenced, for example, should a vehicle pull out of an intersection ahead.

Learning a complex task involves three phases:

1. Cognitive Phase.

2. Assimilative Phase.

3. Autonomous Phase.

The cognitive phase occurs when a person learns that to achieve a certain goal, for example, to turn left, he must perform a specific action, e.g., turn the wheel to the left, or conversely that a certain action will lead to a specific result or chain of events.

During the assimilative phase the individual practices what he has learned or observed until such time as he knows automatically how much, when, and in what direction he must move the wheel - autonomous phase. Now a different set of priorities may be assigned as the capacity to process information has gradually been increased and the attention required to perform the task has been compacted. This is a continuous process in learning. When learning to fly an airplane for example, one's attention is so taken by the amount of information bombarding him that it is difficult to hear instructions - the cockpit is one of the worst classrooms there is!

This process is not only psychological, but has an electro-physiological basis. For example, early studies using rats showed that EEG (electroencephalograph) changes occurred in rat brains with changes in information priority. A male rat had electrodes imbedded in its brain and while in its cage was presented with a clicking sound. With each click there was an excursion of the EEG - an electrical impulse. However, when a female rat in heat in another cage was placed nearby, the electrical excursion ceased, indicating a change in priority circuits.

MEMORY

Since many of the responses in a complex task are based upon experience and memory it follows that memory holds an important place in the system. To this end there are two basic memory stores, short-term memory (STM) and long-term memory (LTM).

1. **Short-Term Memory (STM)**

   STM is a limited capacity electrochemical store. Items are stored only for short periods of time (less than 20 seconds) and only about seven items may be maintained in STM at one time.

2. **Long-Term Memory (LTM)**

   This is thought to be an anatomical store, that is to say, effected through changes in synaptic connections between neurones. The number of neurones in the brain does not increase, but the interconnections can change. Some investigators claim to have demonstrated an increase in brain weight with learning probably as a result of changes in LTM storage (Ref. 32).

   In capacity LTM is truly remarkable. All information such as names, shapes, symbols, music, etc., are stored here. It has been demonstrated through hypnosis that information received even before birth may be stored in LTM. Although items in this store are resistant to decay, access may be difficult under certain circumstances and may be modified by such factors as emotion, defence mechanisms, or stress. It is more resistant to psychobiologic decline (aging) than STM as evidenced by elderly persons who may not remember something which occurred only a few seconds previously, but remember details of their childhoods, for example.

   Information of a high priority nature may be fed directly into LTM store.

EFFECTORS

Once a decision has been reached, action may or may not be taken. This may be in the form of a verbal exchange or manipulation of some control resulting in a change in behaviour of the overall aerospace system.

Feedback to other elements of the information processing system may occur, and as we shall see later, the central processing channel may be bypassed.

It may now be visualized how this system fits into the man-machine system, and closes the loop at the man-machine interface between the displays and controls.

There are, however, several fundamental weaknesses to this system in addition to its being vulnerable to degradation by stress:

1. The quality of information may not be adequate to fulfil the requirements for successful and unhindered operation in the aerospace environment. We have examined the sense of vision to illustrate this point.

2. It is a single channel system with a limited capacity for handling information.

3. There is a time delay between perceiving information and responding to the stimulus. In a healthy young individual this may be as long as 3.4 seconds when one considers all of the built-in delays. For example, it takes time for a nervous impulse arising from the retina to travel along the optic pathways to the visual cortex which, unfortunately, is located in the occipital lobes of the brain, about as far away from the retina as you can get.

   If a person is trained to respond in a reflex fashion the time may be reduced to less than one second provided that the stimulus is expected. This is one rationale for simulator training which reduces complex tasks to reflex responses. Simulator training also "frees up" some capacity for dealing with further information. This is called "Spare Mental Capacity".

4. Mental Set or Expectancy may modify what we perceive. The following sign is a good example:

Fig. 4-2

Most people when reading this for the first time will fail to spot the second "THE". According to the laws of physics both THE's are focused on the retina but one has been eliminated by the time it has passed through the system.

An analogy in aviation occurs all too frequently - the harassed light twin pilot who forgets to lower his gear even when reminded by ATC. He will look at the warning lights and see "three green" even though they are red and will swear on a stack of Bibles as high as he is that they were green. Lie detector tests will often bear him out on this even though laboratory examation shows that the red filaments were burning at impact.

Language is another area where expectancy is constantly being used. When listening to someone it does not take 3.4 seconds to understand what he is saying. This is because one is constantly anticipating what is to be said next, a tendency which may lead to false hypotheses especially in conditions of marginal stimulus perception, such as in a noisy environment or where a second language is used (Ref. 30). This may result in misinterpretation of verbal information in cockpit communications or exchanges with ATC.

5. Man has a limited attention span. When man first descended from the trees he was in constant danger from other animals and environmental hazards which might result in harm or death. Therefore, those who were the best environmental scanners survived and natural selection therefore resulted in a nervous system which continuously surveys the environment and lags on any given item for very short periods.

   Unfortunately, a machine demands attention continuously and we are unable to satisfy this requirement. In fact, we have gone one step beyond in automated systems where we have assigned the primary task to the machine and relegated man to a monitoring role, one of the things he is poorest at doing. Once the captain of the ship, the pilot now is required to try to watch it and ensure that it continues to function - which it usually does. When a malfunction does occur, this demotivated, bored individual may not be capable of assimilating all of the information in time to take over the situation and recover successfully.

   Perhaps man should be hand flying during certain critical periods such as approach and landing, with the machine monitoring him and nudging him should he fly outside of certain parameters. Thus, his state of arousal would be maintained at a more optimum level and he would remain more motivated.

MENTAL TIME SHARING

It is obvious from previous discussion that not only must the appropriate information be selected for processing but that it must be processed at a given rate in order to satisfy the demands of the task, the rate depending upon the task in question. Since the brain functions as a single channel system, it cannot be "dedicated" to any given element of the task as a whole.

In this respect the brain is analagous to a computer set up. One computer may have numerous terminals with an operator accessing the computer at each terminal. To each operator it would appear that the computer is one hundred per cent dedicated to his demands, but what the computer is actually doing is slicing up time and allowing itself to be accessed by the operators in a distribution fashion which is ordained by some pre-determined priority system. Psychologists have called this as it applies to the brain "mental time sharing" or "mental time slicing".

Naturally, there is some limit to the speed at which the brain may slice time, i.e., handle information. In a healthy 20-year-old, this is approximately on the average of 13.6 items per second, which declines in the 45-year-old to approximately 10 items per second (Ref. 31). The rate of information processing is, along with filtering, extremely vulnerable to degradation by other stresses such as hypoxia, alcohol, fatigue, and various toxicological products, for example, carbamate and organophosphate insecticides.

ABILITY VS DEMAND

Any task demands a certain level of performance. Failure to meet this demand will result in failure of the task, in the case of flying a possible castastrophe. A

chimpanzee could probably be taught to handle the controls of an aircraft but he could never learn to be a pilot because he does not have the capability to deal with the unexpected - this is one major factor which makes a pilot. Therefore, one of the aims in training him is to overtrain him to the extent that the routine tasks are compacted and he possesses a large "spare mental capacity" to handle other tasks. The training, therefore, takes him up to a level of performance which exceeds the level demanded.

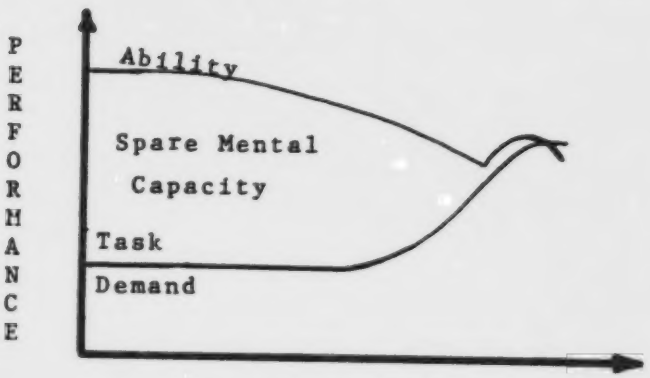


Fig. 4-3

Of course each individual has his limit in terms of biologically available capacity and one of the aims of selection is to select individuals who are capable of developing a large spare mental capacity. Conversely some tasks demand much higher levels of performance than others, resulting in a smaller spare mental capacity. As we'll see later, the demands made upon a helicopter pilot are very high, particularly in reciprocating helicopters where the management of r.p.m. is primarily manual.

As stated before, rate of information processing which is one of the fundamental building blocks in a man-machine system, is extremely vulnerable to stress and fatigue and may decay insidiously through the course of a flight as a result of noise, vibration, hunger, fatigue, boredom and other stresses. Unfortunately, especially in fixed wing flying, the maximum task demands often occur at the end of a flight, when performance has decayed the most. As the approach and landing sequence is reached, spare mental capacity is often at its lowest. This may be offset to a certain amount by anticipatory stress (arousal).

The Jerkes-Dobson curve illustrates the relationship between arousal and performance. It can be seen that as arousal increases, performance improves up to a point. With over-arousal performance begins to wane and may decrease to levels which seriously impair the individual.

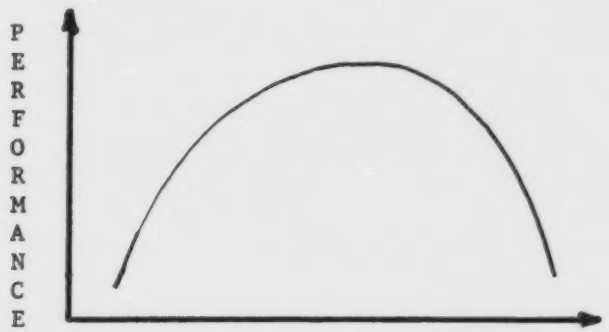


Fig. 4-4

Nicholson in the U.K. (Ref. 33) found that a pilot's heart rate reaches a maximum just after touchdown. Let downs which involve poor ATC and inadequate navigational aids often lead to profound cardiac acceleration and gross finger tremor, especially if complicated by unfavourable meterorological conditions. "Adverse circumstances give rise to considerable elevation of central nervous system arousal which could lead to a situation in which performance on the flying task becomes impaired."

Even with some augmentation from anticipatory stress it may be seen that we are now in a situation of lowered spare mental capacity where presentation of further information or the addition of another stress may result in system overload. What can happen to the mental function of the human operator in these circumstances?

Vinson and Grey-Walter have developed tests which test spare mental capacity (among other things) by progressively increasing the mental time-sharing demands to an overload state. Dongier at McGill has shown that a collapse of certain brain waves occurs when this state is reached (remember the poor male rat). Several things can happen at the point of overloading (Ref. 35):

1. Omission - simply not processing information.

2. Error - processing of information incorrectly and then not making the necessary adjustment.

3. Queuing - delaying responses during peak load periods and then catching up during lulls. Here the responses are not necessarily priorized, but settled in order of arrival.

4. Filtering - the systematic omission of certain categories of information.

5. Multiple channels - synchronizing responses to more than one task so that comparable responses can be made at the same time.

6. Approximation - producing a less accurate response because there is no time to be precise.

7. Coning of attention - as the stress or workload increases, the individual's attention is more centrally orientated. For example, he may be so distracted by a chip detector warning light that he forgets to perform other essential tasks, like avoiding obstacles.

8. Escape - the pilot may simply give up or freeze and calmly watch the ground come up.

9. Regression - human beings under stress will often regress to a pattern of behaviour which was learned at an earlier time. I would like to illustrate this with a personal experience:

   In early 1980 I was being checked out in a Bell 206B. During the trip some sudden violent control feedbacks occurred making my instructor (Hugo Leech) and I somewhat nervous. (Helicopter pilots develop a deep suspicion of mechanical things.) Hugo took control and asked me to turn off the hydraulic boost switch. In a flash my hand was on the main fuel switch. Had I activated it we would have been in the trees. Why did I do it?

   When I got back to my office I looked up a panel diagram of the OH-58-A on which I originally trained in turbine helicopters. Guess where the hydraulic switch was. Right in the same location as the main fuel shutoff switch. Even after eight years of not flying a 206 I had reverted to a previously learned response. This illustrates the requirement for standardization of cockpit layouts, as well as how easily a pilot can be misled to commit an act which could have disasterous consequences.

Even though systems become more sophisticated, accidents continue to occur as a result of information overload. I think that this may be a result of having pushed man beyond his capability to handle the information or, in the case of automation, removing the motivating factors which maintain his interest and, therefore, his arousal with the same net result. Professor John Clake in Winnipeg has informed me that in order to drive a car one mile, approximately 12 000 pieces of information must be considered. At 60 mph this means that the rate of processing must be increased to 200 pieces per second - a human impossibility. Reducing the speed limit has a tendency to reduce the number of accidents (in addition to the severity) supporting this hypothesis.

Selection of candidates for aircrew is important. As stated earlier, the most important building block is capability of processing information. If this is within limits, then other factors can be considered.

In this Chapter, I have attempted to show how man functions as an information processor at the man-machine interface level. I have shown how marginal this capability is and how vulnerable it is to performance degradation. Now let's move on to discuss some of the factors which may adversely affect performance and under which the helicopter pilot must operate.

CHAPTER V

PHYSIOLOGICAL ASPECTS

Now that the fundamentals of how helicopters are put together and what forces act upon the machine during flight are basically understood, some of the physiological problems facing helicopter pilots may be appreciated. In general, these can be broken down into environmental stresses such as: flicker, noise, vibration and cockpit contamination and operational stresses such as disorientation and visual problems, which will be presented in the next chapter.

Flicker

One of the phenomena quantitatively more predominant in helicopter flight than in fixed-wing flight is flicker. This is produced when light from the sun or other source is interrupted by the revolving blades or, it may occur at night as a result of the Grimes light reflecting on the disk. Flicker stimulation produces effects varying from mild discomfort and fatigue in most, to unconsciousness and frank convulsions in very susceptible individuals. Few studies in a laboratory environment have reproduced flicker vertigo or unconsciousness (21) but many incidents have been recorded. Forbes (13) describes nine well-documented, and in some instances, famous cases of flicker-induced phenomena in his article, "What is Flicker Vertigo?" in the U.S. Army Aviation Digest. In addition, I personally have experienced at least one episode of flicker phenomenon and have witnessed one well documented episode.

CASE 1 — While proceeding by helicopter to a crash site, the author was assisting the pilot by map reading and navigation. Since we were flying down sun, the shadow of the rotors was falling on the map, the ensuing flicker resulting in blurring of vision and loss of fusion or binocular vision. It seems that a flicker frequency of about 8 cycles per second can cause incoordination of the extrinsic eye muscles resulting in loss of binocular vision, a condition which can be easily reproduced with a strobe lamp. As soon as we changed heading, so that the shadow no longer fell on the map, the discomfort disappeared.

CASE 2 — While flying in formation, a 32-year-old pilot with about 1600 hours of helicopter flying time, noted a flicker on the right hand inside aspect of his visor, produced by light passing through the vibration dampers (see Fig. 2-4). This was aggravated by a dusty visor and produced some confusion as to position as well as blurring of vision, plus loss of fusion when glancing to the right. Change of direction obviated the condition immediately.

That flicker modifies various neuro-physiological processes is well known and quantitative analyses have been performed. It seems that the critical levels lie between 3 and 30 flickers per second (Hertz). Six to eight f.p.s. result in diminished depth perception. Nine to 15 Hz produce subjective effects, while levels in the order of 25 f.p.s. reduce concentration and may cause fatigue.

During the Second World War, the Nazis set up their searchlights to flicker at a frequency of between 4 to 12 Hz in order to aggravate attacking allied bomber pilots. In contemporary times, discotheques have utilized flickering lights to produce a form of disorientation among customers of such establishments, particularly disorientating their concepts of cash/value in some nefarious way.

It should be mentioned here that all of the various types of flicker induced phenomena are aggravated by alcohol and certain drugs. It must also be emphasized that persons with a hangover are particularly susceptible to flicker phenomena.

Noise

Noise, though a problem in all aircraft, is more pronounced in helicopters. Reasons for this are threefold:

First, because the power plants are required to produce lift as well as thrust, they must be larger in relation to the size of the airframe than in fixed-wing aircraft. Also, due to basic design it is not as easy to isolate the power plant as it must normally be close to the centre of gravity.

Second, there are more noise-producing mechanisms in helicopters. These include, besides the engine, the transmission, main and tail rotors, tail rotor gear box and drive train. These items generate noise over a fairly wide spectrum.

Third, for comfort or to satisfy operational requirements, helicopters often fly with doors off. The presence of armament in military strike helicopters adds an additional noise source and the sound pressure levels in combat helicopters may rise to 140 decibels when the guns are operating.

The type and spectrum of engine noise depends upon whether the helicopter is equipped with a reciprocating or turbine engine. Noise generated by a reciprocating engine falls mainly in the lower register at fairly high sound pressure levels, for example, 115 decibels in the Hiller CH112. One feature of reciprocating engine noise is that it consists of a series of explosionary impacts in contrast to turbine noise which is a more steady type, again with high sound pressure levels but usually in the higher frequencies.

Transmission noise tends to be generated in the lower frequency range and consists of a loud rumble accompanied by a loud whining sound. Without ear defenders one suffers subjective drowsiness and is left with tinnitus and a temporary hearing loss following a flight. Repetitive prolonged exposure will eventually result in permanent neuro-sensory hearing damage.

There are, of course, other noise generators in helicopters such as the rotating beacon, fuel pump, gyros, radios, etc. All of the sounds from these various components are combined to produce a cachophony which can result in various physiological disruptions if protection is not used. Analysis of sound pressure levels are high in all octave bands, some of the values being as high as 114 decibels. Most of the values exceed 85 decibels, which is the highest level in the optimum range where ear defenders are not necessary. In the interest of hearing conservation it is

therefore essential that air and flight line crew employ sound attenuation devices during helicopter operations.

In addition to causing acoustic trauma mentioned above, noise has other short and long-term effects. It is well known that food may be cooked in ultrasonic ovens as a result of imparting increased kinetic energy to the tissues when exposed to this form of sound energy. Physiological symptoms and effects probably occur through similar mechanisms and result in brain irritation which produces a number of observed phenomena. High sound pressure levels in the order of 140 decibels may result in nausea, vertigo, nystagmus, incoordination and unconsciousness. Lesser sound levels may result in reduced consciousness, drowsiness, reduction in attention span, irritability, and fatigue (29). Modern rock groups utilize loud noise to "turn people on". Some teenagers state that when exposed to the turned-up amplifiers of an acid rock group they become euphoric. However, many adults become irritable when exposed to the same noise. Only the deaf remain unaffected and even they can sense the vibration.

Vibration

Vibration is similar to noise in that noise is basically a high frequency, low amplitude vibration. Guignard (29) has defined vibration as being a sustained structure borne disturbance applying a translatory movement to the body and perceived by the senses other than hearing, (that is, vision, vestibular or tactile senses). A moment's reflection will disclose the practicality of such a definition.

The frequencies and amplitudes of vibrations in helicopters are varied and are produced mainly by the engine drive train and rotor assemblies, though aerodynamic forces may also produce vibrations. The vibrations produced occur in vertical, longitudinal, and transverse directions. Earlier helicopter types are very prone to vibrate and even the latest models still vibrate significantly. As an example, the Bell 204 Huey has a peculiar "hump" type of vibration which is quite noticeable during cruise. The majority of vibration figures given for helicopters fall in the range of from between 25 to 75 hertz, with an amplitude of about 0.008 inches which is within the discomfort zone. Under certain conditions in the Hiller Nomad, vibrations in the order of 6 hz, 12 hz, and 108 hz occur frequently, the latter originating in the tail rotor drive train.

Performance during vibration stress is influenced by the differential vibration between an individual and the task being performed (25, 29, 15). Continuous vibrations of 20 Hz in aircraft are not acutely harmful, but may cause discomfort and fatigue, while those in the range of between 1 and 20 cycles per second can cause physiological damage and hinder performance. Vibrations or oscillations below a frequency of 1 Hz generally result in motion sickness. One has only to fly a helicopter for a prolonged period, say 5 to 8 hours to appreciate the discomfort, particularly in the back and shoulders, which results from vibration.

Minimum tolerance to vibration is found in the 6 to 8 Hz range due to amplification by resonance of this vibration by body tissues and organs. The human body experiences a natural resonance in the frequency range of between 4 to 8 Hz. This amplification may cause accelerations within the cranium to be as much as three

times greater than those at the seat. It can be readily appreciated that vibrations in this range may have adverse effects and can contribute to permanent trauma of some of the delicate organs located within the cranium.

Visual acuity is adversely affected by vibration at frequencies of roughly 4 Hz and higher, and loss of binocular vision occurs in the range of 8 Hz. The latter is believed to be due to interference with the neuronal transmission to the extra-ocular muscles which occurs at a frequency of approximately 8 Hz. Damping by body tissues may result in a vibration differential between the instruments and the head, and visual impairment may result. This effect is more marked under red lighting conditions, probably due to "red light myopia", and red lighting on a helicopter instrument panel may therefore be less effective than white lighting. Speech impairment may also occur if one is subjected to vibration in the 4 to 8 Hz frequency range. In addition, tactile senses and kinesthetic senses (limb position) are undoubtedly affected. Currents in the semi-circular canals causing excitation of the vestibular senses result when one is subjected to vibrations under 1 Hz. Vibrations in the order of 3 to 12 Hz may result in decreased tolerance to disorientation.

More chronic pathology may result from prolonged exposure to vibration (29). Changes which include osteoarthritis, traumatic fibrositis, disk herniation, coccygodynia and lumbosacral pain may result. More acutely, exposure to vibration above the tolerance level in the body resonance frequencies may result in abdominal pain, chest pain, testicular pain, shortness of breath, anxiety, general discomfort, urgency to micturate or to defecate, voluntary and involuntary muscle contraction.

The most common subjective complaints seem to be fatigue, diminished performance, and back pain. One of the factors affecting the development of back symptoms and back pathology is the posture while flying. Pilots tend to sit hunched forward, right elbow resting on the knee, with the head erect. This results in shearing stresses being applied to vertebrae in the lumbar, upper thoracic, and lower cervical regions. Often this hunched posture is due to the fact that the seat cannot be adjusted properly or because the cockpit is too small to sit erect. Few helicopters have adjustable seats and more attention must be given by designers and manufacturers to the anthropometric requirements in helicopter seat design and control placement. Vibration reducing padding is a must in helicopter seats.

Cockpit Contamination

Cockpit contamination is a problem almost unique to helicopters, particularly during hover manoeuvers, since in this configuration they are literally wallowing in their own excreta. For example, the normally acceptable limit of carbon monoxide, pollution is 100 parts per million, but the tolerance level diminishes with altitude. When the United States government purchased the H37 helicopters, carbon monoxide levels ranging from 1000 parts per million to 2000 parts per million were found. Careful examination disclosed that exhaust fumes were being drawn in through the heater intake duct. Manufacturers have, of course, taken steps to remedy this problem by repositioning exhaust manifolds, etc. In the CH112 Hiller, it is standard operating procedure to turn off the auxiliary heater except while in translation or cruise flight lest cockpit contamination occurs. I myself have experienced nausea and headache from forgetting to turn off the heater during a hovering exercise.

In my opinion, some form of carbon monoxide detecting device should be placed in every helicopter cockpit. In addition, more efficient forced air circulation systems should be installed. Care must be taken, of course, in placement of the inlet ducts, to avoid ingestion into the cockpit of recirculating gases.

CARBON MONOXIDE ACUTE EFFECTS

DURATION OF EXPOSURE - 1 HOUR

Atmosphere Level ppm	%HbCo	
400	7.2	Nil
800	14.4	Headache, breathlessness with exertion
1600	29.0	Confusion, collapse on exertion
3200	58.0	Unconsciousness
4000	72.0	Profound coma
4500	81.0	Immediate death

Fig. 5-1

Ventilation and Temperature Control

Heat and cold stresses are not uncommon in helicopter cockpits, especially those designed with a large bubble which acts exactly like a greenhouse. Particularly in winter when wearing heavy clothing does this become a problem. When the temperature is around 20 to 40 degrees F. the cockpit may become very hot during hovering if there is no forced air ventilating system. In the Kiowa, studies have been performed measuring microclimate in the pilot, co-pilot, and passenger areas and these studies have found that there is a significant heat stress placed upon the crew and passengers during hot weather. The studies have concluded that the ventilation provided to the crew and passengers is marginally adequate. In high wet bulb globe thermometer (W.B.G.T.) environments above 85F., it is recommended that the minimum air flow velocity (to provide adequate cooling) be at least 500 feet per minute; but, it was found that during a hover, the velocity over the pilot's face, chest, and legs was less than 100 feet per minute. The ventilation in the passenger area was less than 100 feet per minute even at cruise, with all of the vents open and heater fan and defogger on (18). It is obvious that more attention must be paid to providing adequate ventilation systems in helicopters, both for the safety and comfort of the pilot, passengers and crew.

During winter operations in the CH112 Hiller, for example, special panels or shrouds are added around the engine area to maintain engine operating temperatures. This necessitates a prolonged pre-flight inspection resulting in the pilot being thoroughly chilled by the time he enters the machine. Particularly if he is doing much hovering on a sunny day, he is subjected to over-heating and excessive perspiration. Following his flight, when he leaves the machine, he again becomes cold. This fluctuation between hot and cold environments places much stress upon the homeostatic mechanisms of the body and may make the pilot more susceptible to respiratory infections, etc.

Hazards to Ground Personnel

One of the factors often overlooked by those involved in the operation of helicopters is the hazard to ground personnel. Aside from the high sound pressure levels generated by helicopters, the effects of downwash may have deleterious effects (24). The following general characteristics of helicopter downwash have been noted when a helicopter is in a hover:

1. Downwash does not produce significant vertical components to the resultant wind when a helicopter is within ground effect. The resultant winds are horizontal at all levels to which a standing man is exposed.

2. The magnitude of the resultant wind is directly related to the gross weight of the aircraft and to some extent to disc loading. The initial downwash velocity is directly proportional to the square of the disc loading.

3. The magnitude of the resultant wind at ground level is inversely proportional to the height above ground of the thrust generator when the thrust generator is within ground effect.

4. The magnitude of the resultant wind is not uniform vertically above a point on the ground. In general, maximum winds are estimated to be between 5 and 20 inches above the ground for most operational helicopters.

5. The height above the ground of maximum winds is directly proportional to the effect of the disc diameter of the thrust generator, and to the height above the ground of the thrust generator.

6. Maximum wind velocities generally are recorded in a circle of radius 1 to 1.5 disc diameters from the centre of impingement.

As an example, the UH-1A Huey has a rotor diameter of 44 feet and a disc loading of 4.34 lbs. per square foot. The maximum wind velocity generated is 3000 feet per minute. Larger helicopters such as the Sky Crane with a rotor diameter of 72 feet and a disc loading of 10.32 lbs. per square foot, may generate wind velocities greater than 10 000 feet per minute. In studies performed by the U.S. Army Aeromedical Research Unit, it was found that the possibility of damage due to primary effects of pressure generated by rotor downwash is extremely remote with our present family of operational and experimental aircraft. For example, the first evidence of structural tissue damage occurs at 518.4 PSF, equivalent to 375 knots indicated air speed. Lung

rupture, due to static over-pressure may occur with sustained pressure with 278 PSF and above. However, the secondary effects of wind pressure can affect man's well-being. These include the injuries to unprotected areas by abrasion from sand and dust and eye injuries due to deposition of foreign bodies, corneal perforation, and conjunctival dehydration. The experimenters recommend eye protection with goggles in winds above 15 knots (about 1320 feet/min.)

The effects of working in downwash was also studied. Calculations indicate that energy expenditures in the range classified as "unduly heavy work" (greater than 12.5 kilo-calories per minute) may be required merely to walk in winds of 50 knots which could be generated by helicopters. In addition to causing fatigue, working in gusty winds of 50 knots will keep a standing man unbalanced, but able to recover equilibrium with effort. On the other hand, gusty winds of 75 knots are sufficient to disturb equilibrium beyond the point of recovery.

The same group of experimenters also investigated the effects of heat loss due to extreme convection. They concluded that wind-chill is severe at winds of 40 miles per hour and could cause hypothermia if prolonged exposure were required. However, they concluded, if in fact a man working within the downwash pattern was generating 10 to 20 kilocalories per minute as a by-product of muscular effort, he would be protected to some extent and therefore although massive convection heat loss is possible, ordinary clothing precautions are sufficient to protect against it. The author notes, however, that these studies were conducted in Fort Rucker, Alabama, where the climate tends to be much more moderate than in Canada. In expected winter conditions the danger of frost-bite can be extreme during helicopter operations due to the wind-chill effects and high wind velocities generated. With some of the smaller helicopters, winds of 30 miles per hour can be expected. At 15 degress Fahrenheit, the wind-chill factor (equivalent temperature) would be minus 19, and at zero degrees Fahrenheit, it would be minus 41. Wind velocities are much greater with larger helicopters and therefore thermal protection must always be a consideration for ground personnel during cool weather. Particular attention must be paid to protecting the eyes, both from the effects of wind-chill and from the possibility of damage by flying debris, etc.

Walking into a tail rotor while the machine is on the ground constitutes a significant hazard. Even persons familiar with helicopters have been known to do this. All ground personnel and passengers should be taught how to approach and leave a running machine. Pamphlets are available from Transport Canada.

Improvement of tail rotor conspicuity will be covered in the following chapter.

CHAPTER VI

DISORIENTATION AND VISUAL PROBLEMS

Disorientation

One of the features of the rotary winged aircraft which renders it so valuable as a vehicle is its ability to move in any direction: true three-dimensional flight. Unfortunately, most helicopters are instrumented to measure velocity in forward flight and vertical flight only. Only the very expensive machines equipped with Doppler instruments can measure rearward or sideways velocity. Therefore, critical situations can arise in certain flight conditions such as whiteout, dark night, or IFR flight. Indeed, analysis of the U.S. Army IFR accidents has shown that the majority resulted from a sidewards impact with the ground(22). Interestingly enough, about 64% have occurred during daylight hours, which may be partly due to the effects of flicker phenomena.

Some of the problems resulting in disorientation occur because of the basic design of helicopters themselves i.e., many rotary-winged aircraft have a large bubble "greenhouse" with absence of the usual crossbar panels at eye level, etc., which a fixed-wing pilot normally uses as an attitude reference. The rotor tip-path plane is often used as an attitude reference but this becomes indistinct under certain conditions and is too variable to use as a reference. During night flying, the disk may not be visible and a problem may arise as a result of reflections inside the plexiglass, e.g., when flying over a light source in the CH-112. In this model, the light slides downward in the visual field as expected, but then a reflection quickly rises upward over the bubble giving a false impression that the nose of the aircraft is pitching forwards. Due to the large area of plexiglass, autokinesis is more prevalent in helicopters. In this phenomenon a light, due to some of the vagaries of our nervous systems, may appear to move spontaneously in any direction. The mechanisms of orientation may be affected by flicker, vibration, and noise, which are pronounced in helicopter flight. It has been shown that most incidents and accidents due to disorientation tend to occur early in an aviator's career so that instrument training should be given early in the curriculum(11). Obviously, aeromedical training designed to help the helicopter pilot recognize disorientating weather conditions, etc. should be provided.

The following tables disclose the phase of flight in which disorientation accidents and incidents have occurred in the U.S. Army experience(22):

Disorientation Incidents

Straight and Level	-	20.3%
Descending Turn	-	12.0%
Climbing Turn	-	11.5%
Taxi (hover)	-	10.5%

Level Turn	-	8.6%
Formation	-	7.6%
Descent	-	5.4%
Landing	-	5.4%
Take Off	-	3.8%
Climb	-	2.9%
Practice Auto Rotation	-	1.3%
Low Approach	-	1.0%
Actual Auto Rotation	-	0.2%
Other	-	9.5%

(Fig. 6-1)

Disorientation Accidents

In Flight	-	44.4%
Landing	-	27.8%
Taxi (hover)	-	16.6%
Take Off	-	2.8%
Overshoot	-	2.8%
Auto Rotation	-	2.8%
Unknown	-	2.8%

(Fig. 6-2)

A problem of very great magnitude is encountered when pilots try to use the artificial horizon as a main reference source. This instrument, as it exists in fixed wing airplanes, is in many ways not applicable to helicopter flight. In a fixed-wing aircraft the artificial horizon indicates a nose-down attitude when descending, and nose-up attitude when climbing. However, the opposite may occur in a helicopter, depending on the airspeed (see Fig. 6-3). Thus, the helicopter pilot must integrate information from other instruments such as the vertical speed indicator (VSI),

airspeed indicator, and altimeter in order to determine whether he is ascending or descending. A computerized readout integrating this information could solve this problem simply.

It is interesting to note that the percentage of disorientation incidents and accidents is very high during straight and level flight which is contrary to what one would surmise. This also brings to attention a separate problem in the area of IFR or VFR night operations. Many of the older reciprocating type machines are not equipped with gyroscopic main attitude indicators so the pilot must rely on his primary instruments such as the needle, ball, and air speed, as well as a somewhat more primitive compass for orientation. Even in some of the more recent designs the instrument layout is poor in that the instrument panel is located downwards and laterally from the forward field of view necessitating head movements when referring to the instruments. In addition, the windscreen area is large and is prone to reflections which may add further confusion for the pilot. These coupled to the fact that a rotary wing machine cannot usually be simply trimmed out to fly "hands off" makes the act of night or IFR flying much more difficult.

Experience levels of pilots involved in disorientation accidents in the Canadian civil population were studied. A series of 55 disorientation accidents from 1976 to 1978 were analyzed. As one would expect there was a peak incidence in the area of 500 hours of experience in all pilots. This tended to drop off and remain constant after 1000 hours of experience, but peaked once more at between 2000 and 3500 hours. When one separated fixed wing from rotary wing it was found that this peak occurred as a result of a secondary peak in rotary wing pilots.

Ross Elliot in his article entitled "Weather Accidents, The Odds" analyzed weather related accidents further (ref. 36). From January 1, 1976, to September 30, 1980, there were 29 known weather related accidents. Whiteout caused 10; flying into fog or low cloud caused 8; loss of visibility in snow, 5; snow ingestion and engine failure, 3; icing, 2; and flight into haze over glassy water, 1. These accidents were results of five other basic factors:

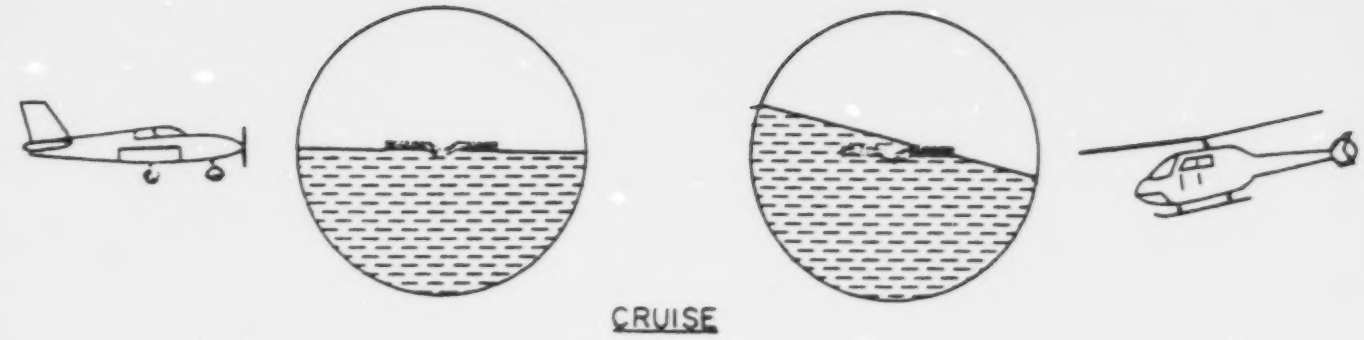
1. Relatively few helicopters are instrumented for IFR.

2. Pilots are often working in remote areas where reliable weather information is difficult if not impossible to obtain.

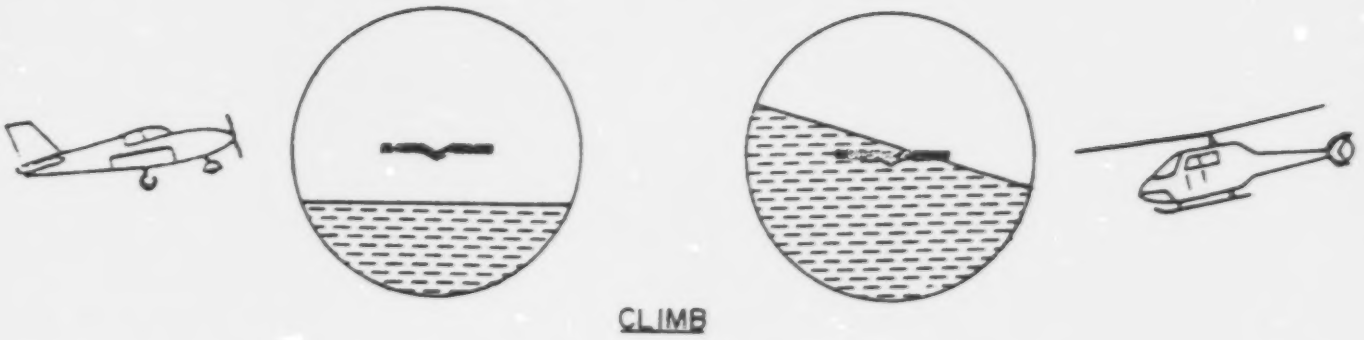
3. The slow speed and high manoeuvrability of helicopters induces some pilots to fly in conditions a fixed wing pilot would refuse to tackle. This may also have an effect in increasing customer expectation and exerting pressure accordingly.

4. Working conditions often result in fatigue which impairs judgment.

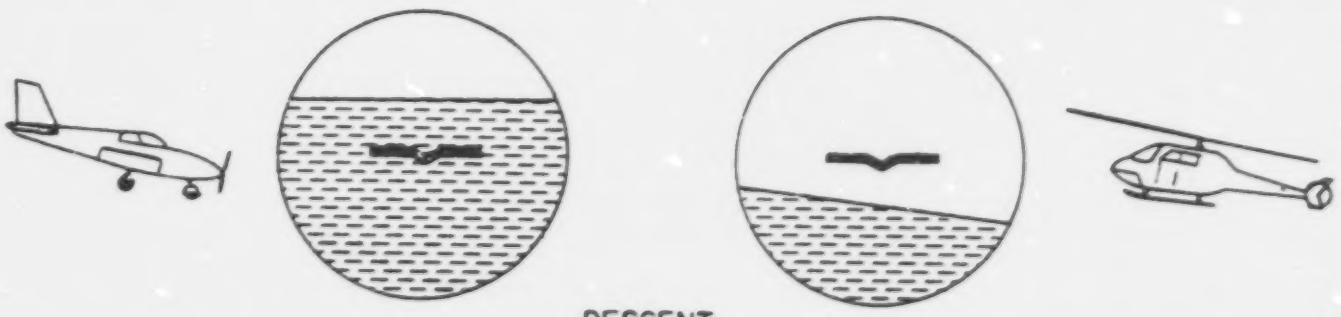
5. Helicopter pilots often work alone without the benefit of supervisory support.



CRUISE



CLIMB



DESCENT

Fig. 6-3

An example of a night disorientation problem is illustrated by the following accident:

In November, 1972, a Bell 206A Jet Ranger with four passengers aboard disappeared while on a night flight in poor weather conditions in northern Canada. An extensive search was initiated but no remnants of the helicopter or trace of the passengers could be found. The following summer, the pilot's body was found on the shore of a lake, and several months later a leg belonging to one of the passengers was found. In addition, several parts of the helicopter, such as the floats, engine shroud and parts of the floor, were found at various times in the lake. Although the main wreckage was never found, some conclusions were drawn from the injury patterns in the human remains as well as from damage to the various parts of the helicopter. It was determined that on the night of the accident the helicopter struck the water in a shallow dive and slight roll attitude at approximately the cruising speed of the helicopter, which is around 100 knots. The weather at the time of the accident was 1500 feet overcast with snow and freezing rain-showers, with moderate icing within and possibly below the overcast. From the medical evidence, it was deduced that the pilot and passengers did not anticipate the impact and therefore this was a disorientation-caused accident. It was noted from the pilot's records that he was not endorsed for night flying or instrument flying, which is not unusual in Canada. As noted before, the instrument panel is somewhat downward and to the left of the captain and not all of the switches are easily accessible. Therefore, some head movements are required to visualize all of the instruments correctly. This could be particularly prone to happen on a dark night, when the pilot would probably be trying to maintain VFR and would be switching his attention from the instrument panel to the outside of the helicopter, which would require a fair amount of head movement.

Visual Illusions

The Leaning Tower Phenomenon:

Some attention should be devoted to the minor types of visual illusions which occur during flight in helicopters. Generally, these illusions do not tend to give rise to problems except during early training, but may give rise to accidents and incidents during certain operations. To understand these, one must understand the visual phenomena which provide cues during flight. While flying straight and level, a visual flow phenomenon occurs that is familiar to anyone who drives an automobile. Objects seem to flow beneath, beside and above the vehicle, spreading peripherally from the central point towards which the vehicle is headed. Initially these objects flow slowly, but pick up speed as the vehicle approaches them, passing rapidly out of the field of view. (see Fig. 6-4).

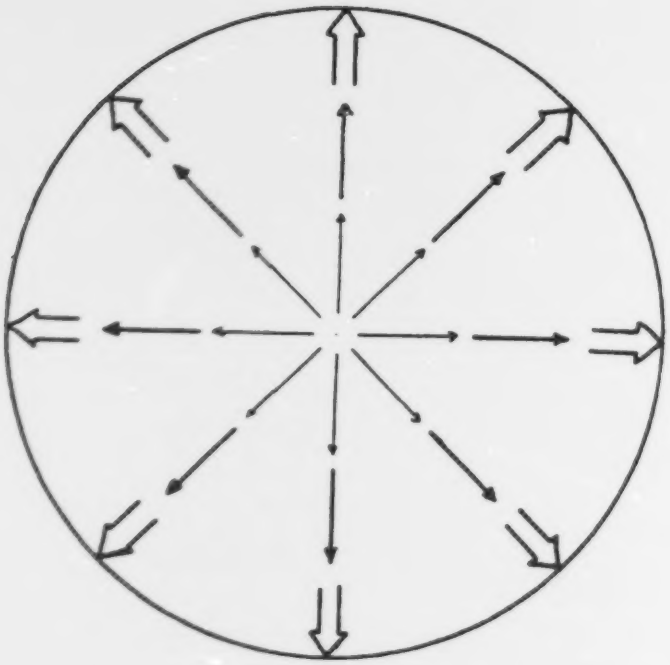


Fig. 6-4

During helicopter training several interesting phenomena were noted by the author:

1. Rearward translation often occurred during lift-off to a hover configuration;

2. forward translation often occurred during descent from a hover; and

3. rearward or forward translation often occurred during pedal turns, dependent upon the direction of the turn.

All three phenomena, though occurring often during daylight operations, occurred at night almost inevitably, independent of the pilot's experience. Therefore, an investigation into this problem was conducted. Through the kind cooperation of the Canadian Armed Forces, night operations of OH-58A Kiowa Helicopters were observed. Thirty-five mm cameras were mounted on tripods at right angles to each machine as it readied for takeoff. During the liftoff phase, the time exposure was taken on Ectachrome X film at F16. Each exposure was started as the helicopter pilot began pulling pitch and ended when a steady hover state was reached.

The lighting on the pads consisted of single marker lamps in front of each machine, with additional lighting being provided by diffused light from the hangar windows and floodlights on top of the hangar. The visual cues in close proximity to the machines consisted of a single low intensity lamp, and the texture and cracks of the concrete illuminated by floodlight, diffused light from the hangar windows, and navigation and Grimes lamps on the machines. It was discovered that all helicopters tended to translate rearward during liftoff from the hover, and an analysis of the light tracks on photographic prints was performed. Two patterns of flight paths were evident, depending mainly upon pilot experience. Photograph (6-1) illustrates the typical straight line profile of an experienced instructor, while photograph (6-2) illustrates the profile commonly observed when a 50-hour conversion student was at the controls. Note that the final resultant angle is roughly the same.

Photo 6-1

Photo 6-2

The average of 10 patterns so analysed was 48 degrees relative to the ground.

Using simple trigonometry it was determined that the average hover height was 4.5 feet and the average rearward translation 4.1 feet. At that time there was standard procedure to rise to a 6-foot hover at night and it was obvious that depth perception was difficult and pilots tended to err on the low side.

Following a briefing regarding the phenomenon of the visual associated cues, the pilots in general were able to decrease their error, the average being 15 degrees from the vertical. However, pilots again tended to err on the low side, as far as hover height was concerned; the average hover height of 4.9 feet resulted in a rearward translation of 1.3 feet.

From the data gathered and from practical experience, it seems that rearward translation, during the rise to the hover configuration, occurs as a result of simple visual illusions (19). That the pilot tends to use references immediately below and in front of the helicopters is further corroborated by the low estimations of height, even though he is being instructed to use the horizon as a reference. In the OH58A, the average fore-aft field of view through the lower nose perspex is about 23 degrees, resulting in a ground-to-eye angle of about 20 degrees at the forward extreme, and 43 degrees at the rearward extreme (Figure 6-5).

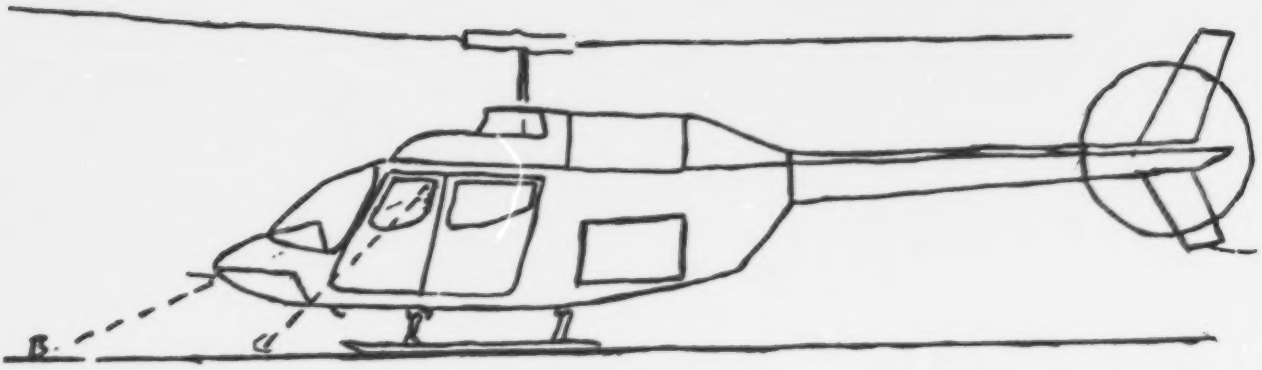


Fig. 6-5

Since the pilot is concentrating on maintaining a level attitude among other things, peripheral stimuli are more likely to be ignored to a greater extent than those in the forward field of view. In rising to a hover, objects immediately below and in close proximity to the helicopter appear to flow beneath the helicopter, resulting in a visual illusion of forward translation, particularly at night, when there may be no or few references above and to the sides of the machine which might help to dispel the illusion. (Photos 6-3 and 6-4 illustrate this illusion.) As a result, the pilot tends to maintain a fixed field of reference and therefore moves rearward as he rises. The pattern, as presented by less experienced pilots, can be explained by the tendency to fly more erratically, or, by the reluctance to apply rearward cyclic when close to the ground. During a relatively rapid ascent vertically, an illusion of forward drift is obtained, and the pilot then moves backward in an effort to regain the same ground references.

Theoretically, a Kiowa pilot with an eye level of 5.4 feet above the ground, using a reference at the near extreme of the lower perspex, would rise upward at an angle of about 43 relative to the ground, resulting in a rearward movement of

$$\frac{6}{\tan 43} = 6.4 \text{ feet.}$$

Therefore, it seems that some apparent forward motion is accepted by the pilot under actual conditions.

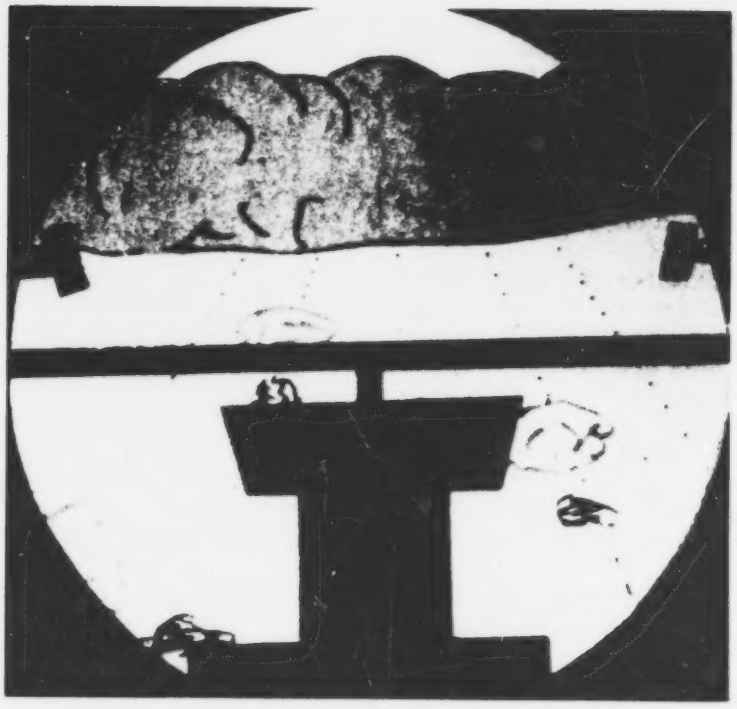


Photo 6-3

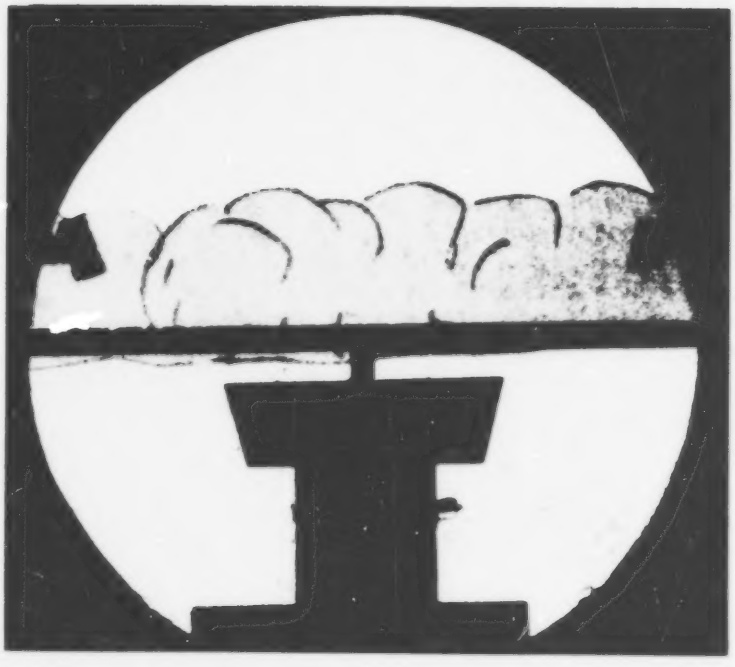


Photo 6-4

This same visual flow illustration may explain the fact that students tend to translate rearward during pedal turns to the left, and forward during right pedal turns. Since a helicopter pilot's vision is concentrated more to the right of his visual field (27), objects close to the helicopter appear to flow beneath when turning to the left, and away when turning to the right. In actual experience this tendency is easily eliminated by being aware of the perceptual phenomena and referring more to objects in the peripheral field of view.

Because of the patterns the light tracks made on the prints, this phenomenon was dubbed "Leaning Tower Phenomenon" and the practical aspects are manifested mainly in flight safety on the flight line, where obstacles may be in close proximity and during confined area operations. A single light source in front of the helicopter does not provide an adequate visual reference for accurate manoeuvering; considerations must be given to providing lighting lateral to the machine. A "T" arrangement, as is commonly used for night operations (see Fig. 6-8), provides better lateral cues if the pilot lands or takes off from beside the tail of the "T". In actual practice, this has been found to be true as the average error (rearward translation) was found to be much less.

Multiple visual cues are required in approaching and transitioning to a hover. One must maintain a constant sight picture in a uniform apparent ground speed. When a proper approach has been executed towards a point, that point will remain steady in the field of vision, other objects appearing to move peripherally. Apparent ground speed is judged by the velocity that objects appear to have as they pass peripherally out of the field of vision. In the final part of the approach, the sight picture must be shifted to a point beyond the sight of intended touchdown as otherwise the helicopter would end up short. As the machine gets closer to the point of intended touchdown, the forward velocity is controlled by maintaining the rate of approach to that area. The mechanisms of performing an approach and transition to the hover are complex and require considerable judgment and anticipation of the pilot, particularly since major power changes are required as the helicopter leaves translational lift and passes into ground effect. This anticipation in judgment is learned by trial and error and can only be gained with experience. At night, five lights are arranged to form a "T", with the spacing and direction relative to wind as indicated in Fig. 6-8.

As soon as the outer lights of the "T" appear to form an equilateral triangle, the pilot begins his descent, maintaining constant sight picture (i.e., an equilateral triangle) and an apparent constant rate of approach to the lights.

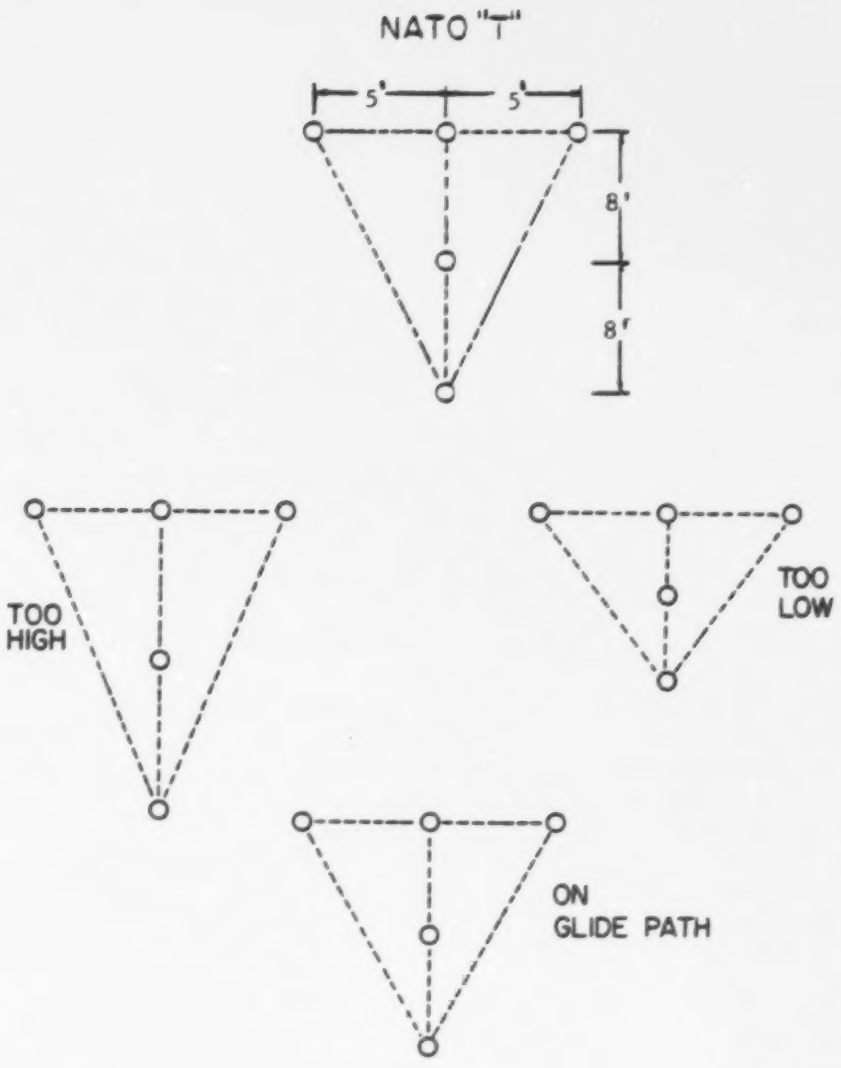


Fig. 6-8

Other Visual Problems

Blind Flying Hood

One problem related to the act of learning to fly a helicopter on instruments is the lack of a suitable blind flying hood design. In helicopters, because of the large area of plexiglass, fixed-wing type hoods do not block out all outside references. Therefore, some difficulty has been experienced in the development of a suitable flying hood for helicopter pilots, where a degree of safety is provided for the safety pilot as well.

Whiteout

Whiteout presents a problem with all types of aircraft and results from lack of discrimination of the horizon due to cloud and a white featureless background. It also occurs in rotary-wing flying when loose snow is blown upwards by the rotors and commonly occurs during winter operations. In fact, during an approach to a hover on a snow-covered field, whiteout due to circulating snow may occur very suddenly without warning (snowball effect). Therefore, most operators perform a no-hover landing on snow-covered areas. Similarly, maximum performance takeoffs are recommended during whiteout conditions.

Presbyopia

Another major problem related to vision lies in the development of bi-focal type spectacles for older helicopter pilots. Occupational bi-focals for fixed-wing pilots have been available for years, but no consideration has been given to development of suitable lenses for older helicopter pilots. Most standard bi-focals have the reading lens on the bottom (see Fig. 6-9) which, because a helicopter pilot must look out through the bottom of the machine (see photo 6-5) so to speak, he is forced to crane his neck uncomfortably.

Photo 6-5

The lack of depth perception through the lower part of the bubble may become very critical during practice autorotations and operations close to the ground. In addition to this, the standard type bi-focal does not allow for observation of the overhead panel, which is quite close to the pilot's head.

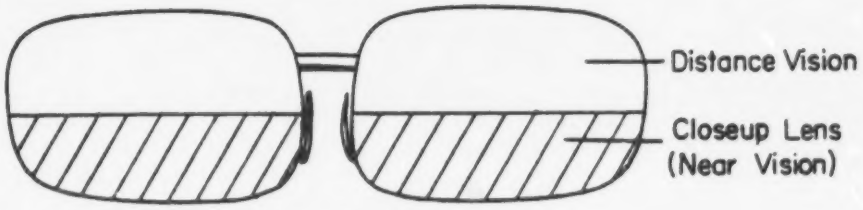


Fig. 6-9

At present, a new design for bi-focal lenses for rotary-wing pilots is being developed by the author. The final configuration will probably resemble Fig. 6-10.

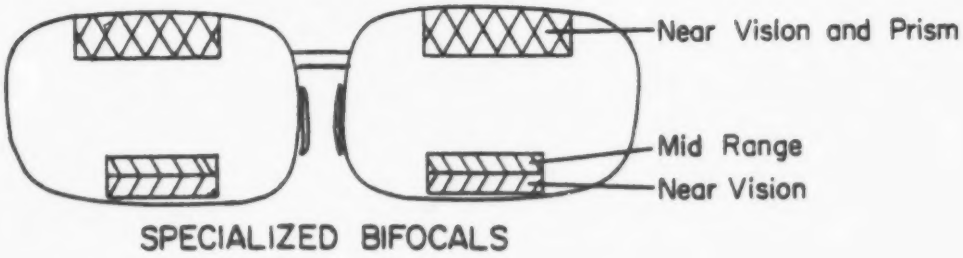


Fig. 6-10

"Break-Off" Phenomenon

Although not as serious a problem as spatial disorientation, characterized by a false perception of aircraft attitude or motion, the "break-off" phenomenon, demonstrated by perceptual disturbances of the aviator's orientation of self with respect to the aircraft or of self with respect to the earth, may result in considerable anxiety to the helicopter pilot. According to A.J. Benson (1), in many of the Royal Air Force

aircrews who were referred for specialist assessment because of disorientation in flight, disturbance of the aviator's assessment of his orientation with respect to aircraft and ground were nearly as common as those in which there were illusory perceptions of aircraft orientation. The feelings of detachment and isolation are most commonly associated with flight at high altitude in fixed-wing aircraft during rather undemanding phases of the flight, but in his paper, Benson describes several cases of "break-off" in helicopter pilots. Of the 29 pilots who described feelings of unreality and detachment in Benson's series, seven of these were helicopter pilots. Two of the pilots experienced symptoms during long straight flights over the sea to off-shore drilling rigs, and two other experienced pilots also had feelings of insecurity and detachment which they first experienced when flying over a featureless sea with a hazy horizon. In one, symptoms occurred at 800 feet and in the other the critical altitude was 3000 feet.

CASE 1 A 48-year-old helicopter pilot with over 3000 hours of flying experience frequently made service flights to off-shore drilling rigs. On one such flight similar to those which he had made many times before during the preceding three years, he had climbed to 500 feet and had set course for the off-shore rig; the horizon was poorly defined because of haze and the sea below was calm and nearly featureless. After flying for about 10 minutes at constant heading and altitude he suddenly experienced a light-headed feeling and that he was out-of-touch with his immediate environment. He became more aware than usual of small movements of the helicopter, but there was no qualitatively false perception of its orientation. No other symptoms characteristic of hyperventilation were experienced, though he became tense and tended to over-control. The de-realization and other symptoms persisted until he saw the off-shore rig and began to descend. Because of this unusual sensory experience he returned to the mainland with a co-pilot and had no further symptoms.

He had no repetition for five months, when, in circumstances essentially identical to the first incident, he again had feelings of unreality. On this occasion he became more apprehensive and felt he would be unable to cope with an emergency should one arise. Symptoms disappeared on landing, although he still felt somewhat ill-at-ease. During the subsequent two days, he made five flights, each one more disturbing than the preceding one. By this time, he was agitated and seriously doubted his ability to fly with safety, so he reported the incident to his medical officer.

CASE 2 A 26-year-old officer with 700 hours of experience in Reconnaissance helicopters was nearing the end of a three-month tour of duty in which he had been engaged in intensive operational duties flying 85 to 90 hours per month. Most of his flying was at less than 200 feet, with frequent

takeoffs and landings. At the end of a typical sortie when he climbed to 1500 feet in order to return to base, he was unexpectedly alarmed by a feeling of remoteness and detachment, which did not disappear until he descended to 200 feet and had a "clear view of the ground". He attributed the incident to fatigue, but symptoms recurred on subsequent flights, whenever he flew higher than 500 feet unless he was close to a cloud and had visual cues of relative motion. The dissociative sensations which he likened to "being a small thing suspended in a great space" were accompanied by a transitory feeling that he was about to faint, but on no occasion was there impairment of control. Nevertheless, he became progressively more apprehensive about the perceptual disturbances and his safety in flight. Two months after the first incident he sought medical advice.

Symptoms of de-realization or break-off may be coupled with a variety of illusory perceptions of aircraft orientation. Most commonly, this perception presents a feeling of instability, though frequently there is a heightened awareness of aircraft motion with exaggerated perception of the attitude, or, change of attitude of the aircraft. In most cases, the phenomenon occurs when the aircraft is flying straight and level, and the symptoms could be misconstrued as being spatial disorientation. Recognition of these symptoms is important, as the break-off phenomenon can be the precipitant of an anxiety reaction in susceptible individuals, and may potentiate the dissociative symptoms in the manner of a conditioned response. The two principle factors necessary for the induction of break-off are a paucity of orientational cues in the pilot's external visual environment and a relatively constant flight path. In fixed-wing aircraft, break-off rarely occurs below 20 000 feet, but in helicopters the lower air speed and the more expansive view from the cockpit without airframe reference may contribute to this phenomenon. Additionally, because the helicopter is an inherently unstable vehicle, control is a more demanding task and may lead to feelings of instability where visual clues are sparse. The author has personally experienced the feeling that the helicopter was balanced on the point of a pin when flying at altitudes above 1000 feet. It also seems that a person is more likely to suffer from acrophobia in a helicopter than in a fixed-wing type aircraft where he feels more enclosed by the cockpit itself.

The dissociative sensations of break-off, even when associated with false perceptions of aircraft orientation, do not appear to present a serious threat to the safety of flying personnel, although the associated anxiety may hinder flying performance. However, it is of great importance to recognize that neurosis and wastage of flying personnel may be prevented by instructing aircrew about these perceptual disturbances.

Improving Helicopter Conspicuity Through the Use of Painted Main Rotor Blades

In 1967, a study was undertaken by the U.S. Army Aeromedical Research Unit at Fort Rucker on improving the helicopter conspicuity by using different colour schemes on main rotor blades. This was done because of the increase in the incidence of mid-air collisions involving helicopters. It should be noted that a helicopter fuselage provides a relatively small profile. It was also found that one of the primary accident-producing situations concerned daytime landings in confined dusty areas (which would

also include snow-covered areas in Canada). Helicopter downwash from lead aircraft often creates a duststorm which partially or completely obscures the airframe and main rotor blades of lead aircraft from the view of follow-on aircraft landing in the same area. The most practical approach to avoidance of these collisions seems to be in the area of visual warning, either by exterior lighting and/or paint applied to the exterior of the aircraft. It was noted that main rotor blade visibility is extremely poor unless the observer is directly beneath the aircraft, which provides maximum contrast of the dark blade against the bright sky. On the other hand, viewing a dark blade against a dark background, as is often the case when viewing from above, decreases the already poor visibility.

There are seven major factors affecting conspicuity of propellers and rotor blades:

1. Colour contrast within the blade colour scheme;

2. colour contrast between the blade scheme and the backgrounds against which this coloured blade is viewed;

3. brightness contrast within the blade colour scheme;

4. brightness contrast between the blade scheme and the backgrounds against which the coloured blade is viewed;

5. the patterning of the various colours on the blade;

6. rotational speed of the blade;

7. size and numbers of the blades.

The experimenters, following their study, concluded that the most effective paint scheme tested included the combination of white, flourescent red, and orange, and black. They also concluded that any paint scheme is better than none at all.

Further studies were performed to determine if painting of helicopter main rotor blades had any effect on photic stimulation (8). Two groups of personnel were studied with a view to determining the subjective effects and the effects on an electro-encephalogram while observing helicopters in flight. It was concluded that there were no adverse subjective effects from flying in formations of helicopters that had painted main rotor blades. In addition, the painted main rotor blades resulted in a secondary value, in that they appeared to serve as an aid in judging accelerations, decelerations, flight attitude, and relative position. The photic-stimulation effects did not constitute a major problem with respect to the development of flicker-induced vertigo. Helicopters with a symmetrical paint design on the upper surface of the main rotor blade did not interrupt the normal operations of the student pilot.

There are, however, other problems related to the most desirable colour schemes on the main rotor blade. It was found, for example, that the fluorescent paint tended to become a gummy-viscous layer that tended to shift position on the blade after coming in contact with the ever present transmission fluid. In addition, in the gummy state the paint tended to attract debris which contributed to blade imbalance

problems. Because of the fact that the paint became faded and ineffective after 2 to 4 months' exposure to sunlight, the maintenance and upkeep costs were significantly increased; therefore, the USAARL recommended that a gloss yellow lacquer be substituted for the red-orange flourescent material. Although the overall conspicuity was somewhat reduced, the use of the lacquer resolved the maintenance problems and was considered a reasonable compromise. In addition, an attempt was made to substitute fluorescent tapes for the painted area. However, this was not found to be feasible due to a tendency of the tape to peel after a few hours.

Tail Rotor Conspicuity

A perennial problem in helicopter operations is having ground personnel walk into revolving tail rotors. Studies were performed by the U.S. Army Aeromedical Research Laboratory in 1972 with the aim of developing a better colour scheme for increasing tail rotor conspicuity(10). The recommended patterns in order of reference were:

1. From the blade tip to the hub, a four-inch area of red-orange fluorescent ("Da-Glo") while dividing the remaining surface into thirds and painting alternately flat black and gloss white. The black and white sections of the other half of the blade are reversed to provide a non-concentric pattern. This scheme is the best provided that "Da-Glo" is repainted every three to four months.

2. Same as scheme in paragraph 1 above, except yellow lacquer paint is substituted for "Da-Glo".

3. Same as scheme in paragraph 1 above, except colour tip is omitted.

Professor T.S. Whiteside of the RAF Institute of Aviation Medicine has recently concluded that offset alternating black and white bands produce better conspicuity.

CHAPTER VII

OPERATIONAL STRESSES

Up to this point, some of the purely physiological illusions and stresses to which a pilot is subjected while flying a helicopter have been examined. It is obvious that a human being is at somewhat of a disadvantage even while riding in the machine for periods of time. Now add some of the more abstract aspects of psychological and operational stresses and the combined factor potential becomes obvious.

Some of the control difficulties resulting from the aerodynamic properties of helicopters have been covered previously. It must be borne in mind that a pilot is continuously calling upon his judgment and experience during a flight, so that the act of flying a helicopter is a mental as well as physical exercise. The pilot must be on his controls 100% of his time and monitoring his instruments by cross-checking frequently due to the critical nature of rotary wing flight.

The flying environment must also be considered: helicopters are often flown in close proximity to trees, buildings, wires, and other obstacles which present a potential hazard. Air currents are often unpredictable around obstacles and must always be a consideration in confined areas. Density altitude, load, and available power are also a consideration. As an example, a reconnaissance and approach to a confined area is examined:

The pilot first makes a high-level reconnaissance from about 500 feet above ground level and determines the following:

1. Wind speed and direction.
2. General layout of the area and the best circuit path, including turning points.
3. Elevation of the landing zone.
4. Obstacles in and surrounding the landing zone and their heights.
5. Flattest approach path available consistent with the wind.
6. Best exit and overshoot paths.
7. Size and shape of the area and whether safe manoeuvering is possible within the area.
8. Aiming point for the approach.
9. Touchdown area.
10. Type of touchdown necessary, that is, normal or off-level.

Following this, the pilot performs a low-level pass at 50 feet over obstacles and some of the above factors are confirmed or re-evaluated. At this point, a rough check of available power may be made by comparing cruise power settings with maximum power settings. Now the pilot may make his approach and land if all seems to be in order.

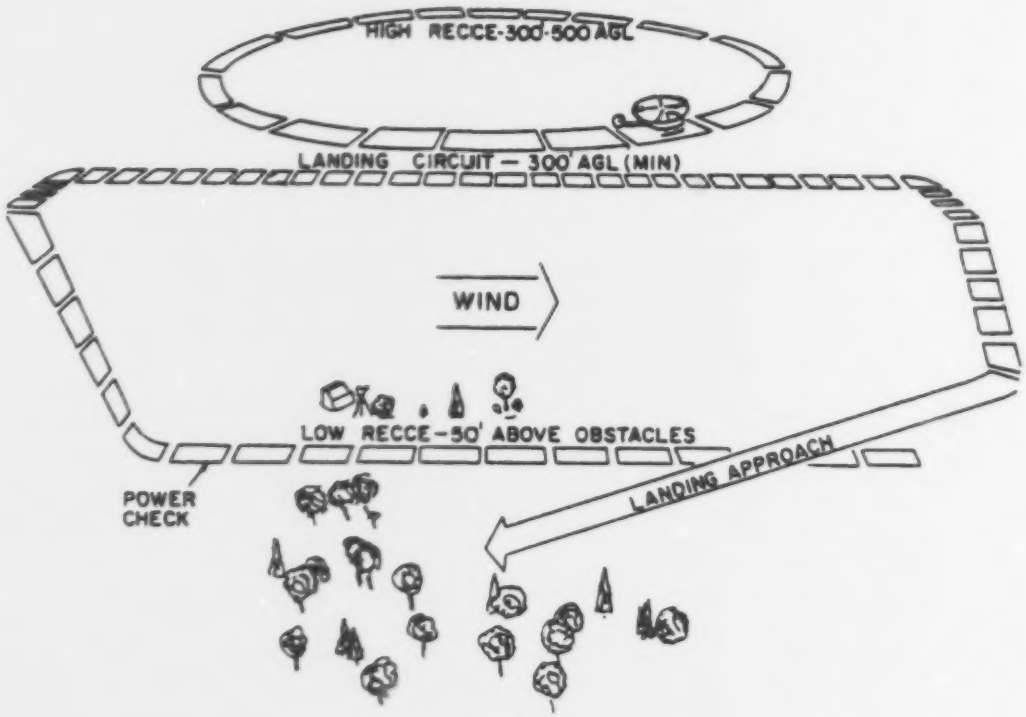


Fig. 7-1

From the above, it can be seen that choosing and performing an approach to a confined area is demanding, particularly in judgment and skill. The pilot is required to approach over obstacles where he knows a misjudgment or engine failure would result in sheer disaster, or manoeuver his vulnerable machine close to objects which could easily chew his rotor to bits. In military operations, the pilot is also faced with the threat of enemy gunfire.

Some work has been done in the evaluation of fatigue on helicopter pilots. In one elegant study performed by Billings et al (4,5), a light helicopter was fitted with a system which recorded rotor RPM, collective movements, cyclic movements, and throttle movements. Four pilots with experience varying from 100 hours to 5600 hours of rotary wing flying were sent on four-hour programmed power line patrols.

The pilots were unaware that their performance was being monitored. As the mission progressed, pilots tended to allow rotor RPM to vary within wider limits.

Control movements of relatively large amplitude increased during the latter hours of flight and after two hours of flying more control reversals occurred. It did not appear to make any difference whether or not the helicopter was being flown within the immediate proximity to obstacles or during cruising flight of a less stressful nature. In fact, analysis indicated that there was a pronounced decoupling of collective and throttle movements during low workload periods. Previous rotary wing flying experience did not have significant effects on fatigue tolerance.

In another study performed by Billings and the same team (2), the physiological cost or physical stress of piloting helicopters was measured by monitoring heart rate and oxygen uptake. It was found that the highest metabolic rates, which occurred during hovering manoeuvers, were approximately twice the resting value. In comparison, it requires 68% over resting values to do an instrument approach in a DC3 or a DC4. About twice the resting value, i.e., roughly equal to that of hovering a helicopter, is required to taxi a DC3. Two things are noteworthy: one, that operational helicopter flying is continuously demanding and two, that experience makes no difference to the above measurements.

Another study, performed by Stern et al (27), analyzed the visual search activity of helicopter pilots while flying. Several factors were noted in this study, including the fact that helicopter pilots, particularly novices, devote more time scanning the right sector of the visual field than the left, (probably attributable to the fact that most helicopters are captained from the right seat). With passage of time during each flight, the following were noted:

1. A decrease of searching in the horizontal plane.

2. A decrease of searching in the vertical plane.

3. An increase in the amount of time not engaged in search activity per unit time.

4. A decrease in eye blinks.

5. Decoupling of eye blinks and eye movement. (In other words, the visual acuity is reduced during eye movements and during blinks, so that the most efficient system would be to blink during eye movements. This is indeed what happens, but the synchronization is lost with the passage of time, so that the visual efficiency is reduced slightly. Although probably not significant from a visual point of view, it may serve as a fatigue indicator and it is interesting to note that this occurred relatively early in a flight.)

Many of the above observations were appreciated and confirmed by the author during his basic course in CH112 Hiller helicopters and will be discussed later.

One of the consistently irritating operational difficulties in rotary wing flying is wind variability; a change in the wind may modify flying techniques to a great extent. An example of this effect is seen in the modification of the technique in performing touchdown autorotations. Ideally, the wind velocity should be about 10 knots to allow

for a normal flare and a good touchdown. "Low wind" conditions mean that the flare must be accentuated, but touchdown ground speeds may be on the high side. "High winds" mean little flare to build up rotor RPM's and a tendency to flare too much and too high. A gust spread of 10 knots is considered to be the limit for safe autorotation to touchdown. While on the subject of flaring, the judgment of flare altitude is difficult since the ideal heights for flares are 75 to 100 feet above ground. It is nearly impossible to judge altitudes accurately above 100 feet AGL.

Winds may have other effects: For example, it is easier to hover in a moderate wind than in still air, but more difficult to taxi cross-wind or perform pedal turns. Transitions from the hover are easier in wind than in calm air because the flapback phenomenon is reduced as a result of the machine being subject to translational lift before takeoff.

Two of the facets of civilian operations which pose a serious flight safety problem are: (1) the number of flying hours imposed upon the pilot and (2) neglect of proper nutrition. In many cases, helicopter pilots are required to fly for 9 to 15 hours per day without adequate rest periods. The Canadian Armed Forces long ago adopted the rule that during instruction a helicopter pilot should not fly for more than five hours per day; for other operations, not more than six hours except in extreme cases.

In the past decade a great deal has been learned about the role of proper nutrition in mental function and in fatigue. It is known, for example, that in order to function the brain must have fuel the same as any machine - lack of fuel means diminished brain function.

The two main fuels for brain function are glucose and oxygen. Depriving the brain of either or both of these two fuels will compromise performance.

Oxygen (O_2)

Oxygen, which comprises 21% of the atmosphere, is absorbed into the blood through respiration and moved via the circulation to the brain. Even though the brain comprises only about two per cent of the total weight of the body, 20 per cent of the volume of each heart beat is circulated to the brain, an indication of its importance in terms of metabolic activity. Unfortunately, the brain is unable to store 0_2 and therefore a continuous supply is necessary. As any pilot knows, the atmospheric pressure decreases as altitude is gained - it is approximately halved for each 18 000 feet of altitude above sea level. Since the percentage of 0_2 remains at 21% this means that the partial pressure is continuously decreasing: at sea level it would be 21% of 760 mm Hg = 160 mm Hg and at 18 000 feet = 80 mm Hg. At 10 000 feet it is 21% of 522.6 = 110 mm Hg.

The partial pressure of 0_2 in the alveolar sacs of the lung may be expressed by the following formula:

$$PAO_2 = PIO_2 - \frac{PACO_2}{R}$$

where PAO_2 = alveolar 0_2 pressure
PIO_2 = inspired 0_2 pressure
$PACO_2$ = alveolar carbon dioxide (CO_2) pressure

R = respiratory coefficient

$PIO_2 = (PT - 47) \times 21\%$

PT is ambient atmospheric pressure and 47 mm Hg is the water vapor pressure in the respiratory passages.

The respiratory coefficient R is the ratio between CO_2 production and loss and varies according to, for one thing, diet. A high fat diet results in an R = 0.85, while carbohydrates result in an R = 1.0 which is more desirable. $PACO_2$ is usually about 40 but may be decreased by hyperventilation.

At sea level the PAO_2 is usually about 103 mm Hg whereas at 10 000 feet this decreases to:

PT = 520 mm Hg
PIO_2 = .21 (520-47) = 100
$\therefore$ PAO_2 = 100-40/R, assume R = 1
$\therefore$ PAO_2 = 60 mm Hg

60 mm Hg is considered to be borderline in healthy individuals and therefore we recommend use of supplementary 0 over 10 000 feet, especially when any physical effort (such as flying a helicopter) or concentration is required.

There is some evidence that effects on the central nervous system as a result of hypoxia (decreased supply of 0_2) to the tissues may occur at lower levels. For example, it is well known that night vision is compromised at altitudes around 5000 feet, and studies at the RAF Institute of Aviation Medicine in the U.K. have indicated that learning ability may be compromised at levels as low as 6000 feet. At levels in the 10 000 feet range the pilot may suffer from drowsiness, fatigue, headache, mild incoordination, hyperventilation, and inability to carry out computations quickly and accurately.

Vinson has demonstrated a decrease in mental filtering ability as well as mental time sharing with mild hypoxia. Unless a pilot lives constantly at high altitude acclimatization does not occur. These hypoxic effects are increased by smoking as a result of carbon monoxide inhalation.

Obviously, caution is necessary when flying at high altitude such as in mountain operations.

Nutrition

The second fuel the brain requires is glucose, which is obtained through a metabolism of carbohydrates (glucose is a short-chain carbohydrate) fat, and protein. Blood levels are regulated by the pancreas which attempts to maintain a constant level though this is rendered somewhat difficult by some of our North American culinary habits.

It is a common habit in the morning to consume with breakfast (incidentally a very important meal for a flier) simple carbohydrates in the form of sugar found in jam, honey, or spread on cereal. This results in a rapid rise of blood sugar which triggers the pancreas to secrete a bolus of insulin and lowers the blood sugar by causing cells to convert it into fat. Because too much insulin is secreted the blood sugar rebounds to a level below that which is ideal (hypoglycemia).

A low blood sugar is detected as hunger or a sensation of lightheadedness, dizziness, nausea and sweating and possibly erratic behaviour. Therefore, about two to three hours after breakfast we have a coffee break and in order to quickly raise the blood sugar many are in the habit of eating a "sticky bun" or candy bar. Although raising the blood sugar quickly, the vicious cycle is repeated time and time again and a condition of stability is never attained.

That accidents may result due to hypoglyemia has been well documented although individual susceptability to the effects of hypoglycemia vary considerably (Ref. 37, page 583). Some patients experience symptoms with the blood glucose level in the range of 75 mg% where others remain asymptomatic at 30 mg%. The first symptoms of hypoglycemia may be psychological, neurological, or mixed and result from not only the hypoglycemia per se but also from secondary epinephrine secretions. Loss of judgment and impairment of insight may occur, and this progresses to disorientation perceptions, restlessness, and even maniacal outbursts. Focal or generalized toxic convulsions may occur and narcoleptic attacks have been recorded.

In the "Pilot Incapacitation in Flight" instructor's manual prepared by United Air Lines an episode subsequently shown to be due to hypoglycemia is described:

"Captain with a particularly good record made a very erratic instrument approach. Broke out at 300 feet in heavy rain. Just before reaching threshold Captain felt he was too high (he was not) and pushed nose over, resulting in a high rate of sink. Crash landing resulted in major damage to the airplane"

In an analysis of 36 cases of loss of consciousness in flight Rayman (Ref. 38) found at least one case of hypoglycemia. Harper and Kidera in their study of hypoglycemia in airline pilots (Ref. 39) also found that some pilots studied did not exhibit symptoms at relatively low levels, whereas, in some, symptoms appeared at higher levels. In some instances the rate of drop of glucose and/or the duration were related to symptomotology. Of 175 pilots given glucose tolerance tests 25% met the hypoglycemic criteria (drop below 50-60 mg%). The blood glucose response in this group was in

general characterized by an initial hyperglycemia at 1/2 to 1 hour and a rebound hypoglycemia at 2 to 3 hours. By the end of the second year of the study 65% of these pilots reported symptoms of hypoglycemia. Symptoms included drowsiness, poor thinking, irritability, tremor, "faintness" and various digestive tract symptoms. One pilot early in the study, who was afraid to report symptoms initially, called in to report that he had to pull over to the side of the road in his car due to mental confusion.

Two cases which compromised flight safety were discussed - the first a 34-year-old first officer who experienced paresthesia and weakness of the left forearm and leg, bilateral scintillating scotoma and mental confusion. The second case was of a 53-year-old captain whose crash landing was described above.

Fructose tolerance tests were performed by the authors. Fructose is absorbed more slowly in the intestinal tract and is less of a stimulus to the pancreas for insulin release. These results strengthen the hypothesis that fruit, which is high in free fructose, could be a safe source of energy for hypoglycemia reactors to glucose.

Ellis R. Taylor studied the epidemiology of aircraft accidents in the USAF (Ref. 40). Lawton reported several cases in which near misses, incidents, and accidents appeared to have resulted from pilot incapacitation due to hypoglycemia. Further investigation led to the conclusion that this may have been the cause of the marked increase in aircraft accident rates in the latter half of the morning as compared to the early half. Improvement of the dietary habits of students was associated with a marked decrease in the accident rates. Hutchison in his study of office workers (Ref. 41) found that consumption of a simple light refreshment during mid-morning and mid-afternoon periods resulted in an improvement in concentration.

Roy Fox, Chief of System Safety for Bell Helicopter Textron Ltd., has found a higher incidence of helicopter accidents in the period immediately preceding mealtime, especially lunch. In my investigation of accidents involving poor judgment I noted that these tended to occur just before noon or after 3 p.m.

L.C. Ou in a study of the effects of altitude on gluconeogenesis in rats found that exposure to high altitude (18 000 feet) first impairs hepatic gluconeogenesis, with the result that gluconeogenic precursors accumulate and hypoglycemia develops (Ref. 42). Impairment of glucose metabolism has been found to occur at relatively lower levels, as low as 5000 feet, leading to relatively low blood sugar levels. Therefore, it is obvious that care must be taken in diet, particularly when working at higher altitudes.

To avoid low blood sugar which may impair performance, I would advise a diet low in simple carbohydrates and fat. In fact protein can be reduced as well. Complex carbohydrates tend to release energy more uniformly (about 2 Cal/min) than simple sugars, and rebound does not occur to the same extent as with sugar. I would recommend frequent snacks of granola or similar substances again avoiding sugars, or fruit, which has been shown to have less tendency to cause rebound.

Fat, both animal and vegetable, should be reduced as much as possible in the diet. Fat may effect hypoxia by changing the coefficient of respiration as shown previously and also results in sludging of red blood cells, which in itself may lead to tissue

hypoxia. Smoking results in hypoxia directly because of carbon monoxide and also results in low blood sugar. Likewise, a hangover state is partially due to low blood sugar and excessive use of alcohol must be avoided.

Unfortunately, the dietary habits of helicopter pilots often leave much to be desired. I have seen tired, hung-over pilots consume an early breakfast of greasy sausages and eggs plus toast and jam, gulp back a quick cupper over a last-minute cigarette, shove a candy bar in their pocket and charge off into the wild blue. With no time for lunch they live on coke and chocolate bars until supper, when they tear into a huge steak and potatoes dripping with garlic butter - certainly the opposite of what would be considered a good nutritional regime for a pilot, or anyone for that matter.

Flight Duty Times

Helicopter pilots are often called upon to work exceedingly long hours in relatively remote areas, where they must also do their own servicing. Often rest facilities are not available or if they are, are often filthy, noisy, and poorly lighted and furnished.

As will be seen in the next chapter, helicopter flying imposes a great workload on a pilot, not only mental but physical. Fatigue is the natural result of continuous exposure to this environment. Because of the inherent difficulty of helicopter flying, duty periods should be shorter than for fixed-wing, contrary to the Bader Commission Report. Aircrew should be provided with clean, airy, bright, well-furnished crew rooms, and proper snack facilities providing fruit and other nutritional foods should be close at hand. Facilities for horizontal rest also should be available.

Because of the high workload involved in instructing, each instructor should be limited to two students, particularly in the pre-solo phase. Students should not fly any more than two trips per day as any more does not result in effective assimilation. Long duty days with split shifts should be avoided, if at all possible.

The above recommendations should be the responsibility of management; decisons to operate beyond normal limitations should not be left to the pilot. Unfortunately, one of the first things to go with fatigue, hypoxia, low blood sugar, alcohol or other toxics is one's ability to realistically and objectively assess one's own capability.

Backache

Although this chapter was entitled "Operational Stresses" it was felt that the problem of backache would appropriately fit into this section as it constitutes a major operational stress and occupational health problem in helicopter pilots. Goede in an article entitled "Backache in Helicopter Pilots" (Ref. 43) noted that a French researcher found that 87.5% of helicopter pilots investigated, all of whom had at least 500 hours, suffered from backache while flying. While the majority experienced pain in the region of the lower spine, the incidence of neck pain was also high. He found that the pains started approximately after 300 hours of flying and were more likely to occur if the previous intensity of flying had been high. In pilots with coexisting spinal disease, the pain appeared between the fiftieth and one hundredth hour of experience. Once the symptoms were established, any flight which was

prolonged or difficult brought on the pain, especially in flights which required considerable concentration by the pilot, for example, confined area operations.

In a 1980 survey of helicopter pilots performed by British Airways, 150 questionnaires were mailed out and 100 replies received. Of those who had forms mailed to them over 50% suffered from backache. Over 50% of those who received forms felt that there was not enough adjustment for the seat to be comfortable. Sixteen of the respondents had backache daily, while 15 suffered from the problem on a weekly basis. Fifty of the respondents found the backache distracting, 13 limiting and 10 incapacitating at times. Twenty-five had been off flying for backache at some time or another. Six respondents found that a lumbar cushion relieved backache completely, while 43 obtained partial relief from use of a lumbar cushion. No particular pattern arose for determining any age, weight or height which might cause problems. In fact, the majority of persons taking part in the survey were in their thirties. People with over 6-7000 hours had a back problem in all cases except one, and even he did not like the seat.

Backache in aircrew has been investigated by Fitzgerald and Crotty (Ref. 44) who found that its incidence in aircrew who have to sit for long periods often without interruption was significantly greater than in ground crews. Thirteen per cent of RAF pilots aged between 20 and 50 years were found to experience backache everytime they flew. Aircrews experienced discomfort, nagging or frank pain usually described as deep and in the midline or the low lumbar region, whereas with helicopter pilots, symptoms were located in the lumbar dorsal or lower dorsal areas, often to the left of the spine. This was believed to have been due to the control position in helicopters, which tends to induce a degree of scoliosis to the left. They found that in over 50% of the aircrew who experienced inflight backache, the sole cause appeared to be within the cockpit, since they became symptomless when removed from the environment. Further findings in this survey showed that there is an initial peak in the incidence of backache between the ages of 25 to 30 years, and a further peak at the age of 40 to 45 years.

Helicopter pilots when flying their machine often sit hunched forward with a scoliosis to the left, in order to hang on to the collective pitch lever, and the right arm bent at the elbow, resting on the knee. In order to see over the instrument panel the pilot's head is tilted slightly upwards, particularly in shorter pilots. The musculature of the back is constantly tense, and a shearing stress is put on the intervertebral bodies as a result of vibration, especially that in the 4 to 8 hertz range, due to amplification by the natural resonance of the human torso.

Adequate human engineering at the time of design of the helicopter would do much to alleviate backache problems.

McCormack (Ref. 45) states that, since much of the time of civilized man is spent sitting down, it is useful to design seats of all kinds to provide comfort and ease at work. The muscles of the body members perform essentially two functions, namely those of the executing movements and of maintaining a position. In the function of maintaining a given position, the amount of muscle activity required depends upon the weight distribution of the position in question. If the body is perfectly erect in the seat for example, maintenance of that posture requires more muscle control than if the trunk is sloping back at an angle. Because of this, chairs or seats should have a

sloping back thereby reducing the muscle power required for maintaining posture, and also reducing fatigue. In studies which were performed it was found that the average angle from the seat to the back that was preferred by people tested was 105.3 from the seat. Since the average seat angle preferred was 6.4° from the horizontal, the total angle of the back from the horizontal was 111.7°. Changes in seat geometry would do much to help the problem.

Ontario Hydro Helicopters operates a Sikorsky S-58 for placing crews and equipment on hydro poles. The pilot is required to sit for long periods of time looking out through the right window when hovering close to power poles. As a result, pilots found that their average tolerance before they became fatigued as a result of backache was in the neighborhood of 1 1/4 hours. Therefore, Ontario Hydro used to have two pilots in each aircraft, one to relieve the other because of fatigue.

Following redesign of the geometry of the helicopter seats in the Ontario Hydro S-58's and the replacement of the foam rubber with an energy damping low rebound type of foam, the problem was largely alleviated. Pilots are now able to tolerate several hours of flying without developing undue fatigue and, as a result, Ontario Hydro was able to change from a two-pilot to a single-pilot operation, which is a saving not only in manpower but also increases the operational effectiveness of the pilots.

A change in position of helicopter controls, along with the provision of adjustable seats, would help. The cyclic control should be close enough to the body and its handle sufficiently low for the forearm to rest on the right thigh. It would be possible to change the axis of the collective pitch lever without altering the safety of the operation. For example, a more vertical collective lever such as is found in the Bell 222 would not only reduce the amount of scoliosis required to reach it, but would also eliminate collective bounce. Goede recommends several measures:

1. There should be adequate medical screening of potential helicopter pilots to rule out existing spinal disease and deformity.

2. Flying hours should be limited to a maximum of five hours per day and fifty hours per month.

3. Helicopter pilots should be provided with lightweight helmets.

4. Rotary wing tour should alternate with fixed-wing tour (military) to prevent rapid accumulation of helicopters hours.

5. Pilots should maintain their ideal body weight to prevent stresses on the spine.

6. Pilots should undertake regular exercise programs designed to strengthen their abdominal and spinal musculatures and increase flexibility.

In order to reduce the incidence of postural backache in RAF personnel Fitzgerald (Ref. 44) devised an experimental contoured lumbar support tailored for each individual. This removed the symptoms completely in 62% of cases, whilst a further 32% improved markedly. As mentioned previously in the British Airways Study, lumbar support did alleviate the problem in a significant proportion of victims. There

are several commercially-available lumbar supports on the market and it would seem that these would be worthwhile in terms of alleviating backache problems. I would recommend use of a lumbar support before the problems begin as backache in helicopter pilots appears to be peculiarly resistant to therapy probably because it is impossible to remove a pilot from the environment which is causing the backache in the first place. These cushions may be held on to the existing back rest with velcro in such a fashion that they are adjustable up and down. In addition, I would recommend that a low rebound energy absorbing foam be used in place of the more spongy type of material which is found in most helicopter seats. There are foams on the market which tend to mold to the buttock, providing uniform pressure rather than pressure points and because of the solidity resist the side to side rolling motion which occurs with softer spongier types of seats. Vibration damping, of course, is an important asset in terms of reducing pathology as a result of vibratory stress.

CHAPTER VIII

"The emphasis in man-machine relationships is shifting from muscle to mental."

PSYCHOLOGICAL STRESSES

The Student

Methods for helicopter training and selection vary from country to country. The U.S. Army has its Warrant Officers' Training Plan whereby students are trained from an ab initio stage. Britain at one time employed a similar system whereby students were flown initially in Chipmunks for 60 hours and then flown in Hillers and Bell 47's for a total of 125 hours. Chipmunk flying was provided with the rationale of providing some air sense and initial selection by the cheapest means. It is interesting to note the graph in Figure 8-1(12), which relates to employing this system, that at ages in excess of 29 years the ability to learn rotary flying diminishes drastically. This is not surprising considering that older people have difficulty integrating 3D tasks. This fact supports the basic premise that helicopter flying is difficult and requires integration of multiple sensory inputs and motor outputs.

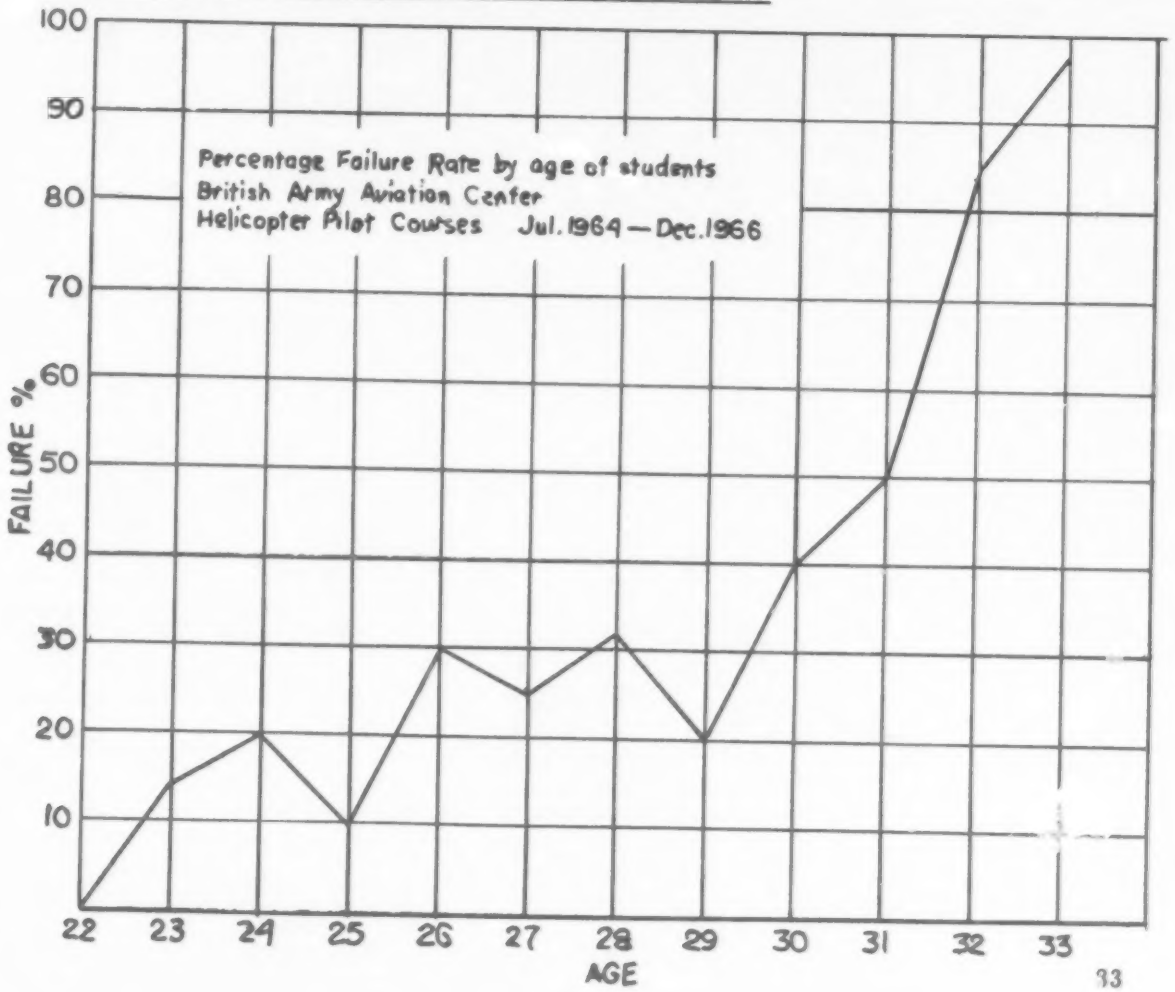


Fig. 8-1

As an example of studies conducted on controlled helicopter student populations the CAF experience might be quoted. In the Canadian Armed Forces, helicopter students are selected after they are qualified to wing standards on fixed-wing types. Following a week of ground school, students were, up until 1972, given 56 hours in the CH112 Hiller Nomad. Solo standard was generally attained by approximately 13 hours of flying time. Canada's success has been much better than that shown in Figure 8-1 presumably because pilots were already experienced. In fact, the author had only seen two failures during his four years' tenure as a flight surgeon. What will happen when the new training scheme is instituted remains to be seen. The new scheme is summarized as follows:

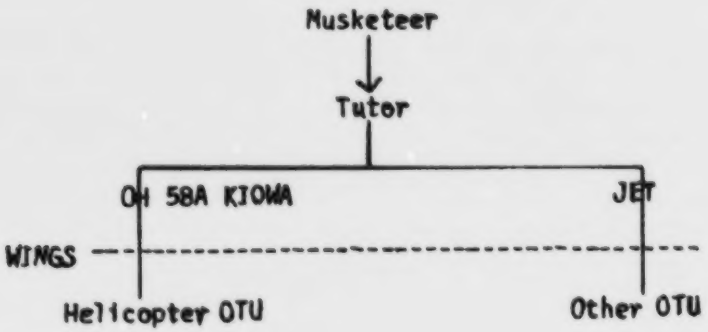


Fig. 8-2

One possible effect is that there will be a change in the student instructor relationship. The pilots will not be fully qualified and the rotary squadron will be tasked with some officer development training. Also, the student and instructor are separated in the Kiowa so that there is not the same type of "intimacy". On the positive side, the Kiowa is turbine powered so throttle control is virtually unecessary and the machine is easier to fly.

It is interesting to observe the students during the various stages of the course. Initially, they may be somewhat bitter and resentful at not having been selected for jet fighter training but rather for a seemingly more mundane role. After a familiarization trip and the ground school, enthusiasm increases. However, following the first few trips in the helicopter, the student develops feelings of frustration and mild depression until solo time. Usually before solo, the pilot may become extremely discouraged at his inability to control the machine and this is usually manifested by depression and feelings of demasculinization. These feelings are particularly noticeable in older, more experienced, jet fighter type pilots, who often seek escape or identity by heavy drinking or sexual acting out. During this phase, simple reassurance by the instructor and confidence gained by observing other students with similar problems is often the best remedy. Most of the above problems result from difficulty in mastering the machine, but a few arise from the notable lack of positive transfer from fixed-wing flying. The pilot carries with him some basic control memories and air sense, but conversion to helicopters is almost like beginning to fly

ab initio. It seems to make very little difference what experience the pilot has because nearly everyone makes the same mistakes, many of which may seem very foolish to the inexperienced pilot. A new pattern of air sense or judgment must be learned and many of the old familiar rules, such as rounding out above the runway, must be forgotten. This may take some time because in emergency situations, even the most quickwitted pilot may revert to a formerly-learned method. This becomes evident when students try to transmit with the starter button (located on the collective lever) or round out during a touch-down PFL or running landing, causing the tail rotor to strike the ground and break asunder. Most helicopter schools have adopted the rule that no student shall partake in any form of fixed-wing flying while he is endeavouring to learn to become a helicopter pilot.

As one example of a student's difficulty, the development of judgment, such as in transitioning to a hover, often causes frank anxiety. To transition, the aircraft is flown on base leg at a specific air speed and power setting. On final approach, when the aircraft reaches 300 feet AGL and the proper sight picture is visualized the pilot then tries to maintain the same sight picture with collective pitch and decelerates to maintain a constant apparent speed over the ground until such time as he is either over the chosen spot in a hover or has touched down in a no-hover landing. Developing the proper technique requires incredible judgment and coordination. Many students become very tense during the approach and brace themselves for the inevitable stall as the aircraft slows down. Naturally, this does not occur. Actually, during some of the latter stages of the transition, the machine is indeed close to or behind "deadman's curve" should the engine fail.

Another period of considerable anxiety and apprehension is the phase of the course where the student is learning touchdown autorotations, particularly turning autorotations, because events occur so rapidly. In addition, a small error of judgment during a touchdown autorotation could result in a serious accident. Confined area operations, because of the proximity of the machine to obstacles, also result in considerable "pucker factor" to the student. At first the areas chosen by the instructor appear to be no larger than a basket ball and until the student learns to assess the size of the rotor disk and gain confidence in his ability to control the helicopter over one spot, he may dread confined area exercises.

Students are not permitted to perform touchdown autorotations solo, but must be accompanied by an instructor. It is imperative that adequate areas be used for practice touchdown autorotations so that the student does not have to concentrate on accuracy during the initial exercises, or at least until such a time as he has confidence in his ability to perform the manoeuvre successfully. In addition, it is also important that adequate separation be given between machines so that the presence of other helicopters does not distract the student from his primary task. Another source of frustration to the student is the variability in day-to-day meteorological conditions. The student may become a bit confused and frustrated because he may be unable to perform a manoeuvre well (one that he considered "aced") because of a change in wind condition. Furthermore, less than ideal conditions may result in long delays between flights or complete cancellation of flying training days, resulting in interrupted training which is undesirable in rotary-wing flying. For each delay, additional time is required to attain a level of proficiency achieved on a previous trip. Factors such as these may have a profound effect on the student's morale and this is often reflected in his difficulty in mastering flying techniques.

While on the subject of learning, some further mention should be made of daily flying times. In the author's personal experience, and having talked to many students, during the first 25 hours, more than two trips in one day's flying program is fruitless. After two trips, the ability to learn is at a low ebb and even the ability to fly suffers due to skill fatigue. This can only serve to frustrate and have a deleterious effect on both the students and the instructor's attitude and morale. Occasionally, after delays in the course, due to weather, etc., these maximums are exceeded, with sometimes detrimental effects on morale. Typical of this, on two occasions, the author exceeded four hours per day (on one day, 5 1/2 hours were flown). At the end of the day, fatigue was so marked that the author went directly to bed without supper. In addition, long cross-country trips are also very fatiguing, partly due to the necessity for frequent stops. It must constantly be borne in mind that a pilot's judgment wanes towards the end of a long trip and therefore it is important to allow for a rest period before he can be expected to perform with precision and safety. Fatigue occurs early in a flying trip, as confirmed by experiments such as those performed by Billings, mentioned in the last Chapter.

Billings and his team, having been satisfied that rotor RPM variability could be used as a quantitative index of pilot performance, performed a further study comparing the rotor RPM variability between helicopter students and their instructors (3). Nine subjects were given primary flight training in helicopters, five of whom were inexperienced private pilots with less than 100 hours of fixed-wing flying time (in fact, two had never flown as pilots) and four were experienced, having from 300 to 5600 hours of fixed-wing experience and multiple ratings. Seven pilot subjects each received 25 hours of instruction, including five hours of solo flying, and the two non-pilots received 20 hours of instruction. The two instructors also had different backgrounds, instructor No. 1 having spent 1 1/2 years as a primary helicopter flight instructor in the United States Army, and instructor No. 2 having been a Marine Corps pilot in Korea and a utility helicopter pilot since that time, but having limited instructing background. Billings hypothesized that instructor No. 1 would manifest lower RPM variability in training manoeuvres than instructor No. 2. Indeed, instructor No. 1 controlled engine and rotor velocity more precisely in all manoeuvres except autorotations involving a 180 degree change in direction. Likewise, the less experienced student pilots manifested significantly greater RPM variability than their instructors, but the more experienced subjects were not significantly different from their instructor except during quick stops. However, during dual flight instruction, it was found that neither group of students was able to control RPM as precisely as the instructors in any of the standard manoeuvres, except taxiing. It was concluded, therefore, that the students manifested greater RPM variability than their instructors during the dual phase of flight instruction, but by the end of training, the experienced students had reached substantial parity with their instructors except during the performance of quick stops. In addition, it was hypothesized that rotor RPM variability would depend upon the difficulty of the manoeuvre. This was indeed borne out by experiment although the differences were less clear cut than had been expected. A difference in rotor RPM variability also occurred during autorotations: straight-in autorotations were accomplished with more precise RPM control than autorotations involving a 180-degree change in direction. During autorotations, where the power was reduced by the instructor without warning, the RPM variability was greatest due to an almost invariable decrease in rotor RPM before the collective pitch control was lowered.

That RPM variability would decrease as the students became more skillful in the performance of their training manoeuvres was also hypothesized by Billings. In general, this hypothesis was confirmed by the experiments. There were, of course, exceptions seemingly dependent upon the student's background. One such exception was an inexperienced private pilot who, despite adequate progress during his fixed wing flight training, had failed his first private test by becoming lost within two miles of the airport where he had trained. During his rotary-wing flight training, he developed a comparatively high level of proficiency very early in training but his performance level decreased as he approached his pre-solo flight check and his FAA flight test. He was extremely tense prior to the latter test and performed poorly, though he was granted the rating. Examination of his flight check data showed evidence of poor coordination, abrupt, erratic control movements, and poor RPM control, accompanied by the highest heart rates observed during these checks.

The other subject who was an exception to improvement was one of the ab initio students whose progress throughout the training was erratic. While he had been able to solo briefly after 17 hours of dual, in his instructor's opinion he would not have been able to meet the army's requirements for primary helicopter flight training. These two cases illustrate the efficacy of using fixed-wing flying training as a screening procedure before commencement of helicopter training, and also point out the importance of the student being relaxed both mentally and physically.

During the same experiment, the nine students had their heart rates monitored by telemetry. Electrocardiographic tapes were taken on the ground before, during, and after flight instruction periods. Billings noted that the post-flight heart rate was generally higher than the pre-flight. Heart rates on the ground tended to increase over the 20 to 25 hours of flight instruction. This trend toward increased heart rate was also observed during dual flights, whether an instructor or student was flying. By contrast, heart rates tended to decrease in most students during solo flight. Student heart rates were highest during flight checks in 8 or 9 subjects. Billings and his group concluded that the above trends were indicative of a moderate and sequentially increasing level of psychological stress. The exception to the sequential trend was solo flying. They felt that these trends might be a reflection of stress induced by the evaluatory role of the flight instructors. However, this author thinks that although this might be true, the type of flying a student does while he is flying solo may have a bearing on the decreased heart rate during solo flights. For example, students are not allowed to perform touchdown autorotations or other manoeuvres which he is marginally capable of performing. This would mean that the student does not anticipate having to perform a manoeuvre which causes him anxiety and therefore is more relaxed during solo flight. It is indeed unfortunate that the helicopter instructors' heart rates were not monitored during the progress of the study as this would possibly have provided a control group.

The Helicopter Instructor

Because of the total unpredictability of the student, the altitude of operation, and the all too small margin for error, the helicopter instructor can never relax. He must always be close to the controls ready to take over in an instant or to counteract any of the variety of errors his student may make. Even late in the course, a student who has been reliable to the point of being outstanding may suddenly, without warning,

make an obvious, simple error, such as increasing power after lowering collective during a PFL, which may damage the machine and which the instructor may construe as being a blatant homicide attempt. Once something goes wrong, there may be too little time to recover and no escape from the machine. In the author's opinion, helicopter instructing is probably the most stressful occupation in flying and although this tremendous stress has different effects on individuals, the instructors seem to pass through several more-or-less distinct stages during their careers as instructors:

1. Initial Thrill Stage

This usually occurs during the first course loading. The pilot has finished his instructor's course and is anxious to make use of his newly-found knowledge and, like Daedalus to Icarus, demonstrate his skills to the student. During his first course, he usually starts off with some anxiety and tenseness but relaxes as the course progresses, blissfully unaware of what innovative stunt the student may pull off.

2. Onset of Anxiety

Stage 2 generally begins during the second or third course. Here the instructor becomes painfully aware of the hazards of rotary wing instruction and is usually very close to the controls and may be over-cautious. Inner conflicts arising from the approach-avoidance situation are manifested in different ways, often in psychosomatic illness, heavy drinking, extreme fatigueability, and irritability. Wives have often commented on how their husbands' personalities have changed during this phase: "He isn't the relaxed, easy-going guy he used to be. Now he comes home, has supper without saying a word, and then goes to bed. When he does speak, he does so unpleasantly." The foregoing was a quote from the wife of a 36-year-old pilot instructor with approximately 6000 hours of flying time and about 1000 hours of operational helicopter flying. The instructors themselves sometimes comment on this in retrospect. Paranoid tendencies accompanied by overt hostility towards students may be manifested in extreme cases.

3. Acceptance Stage

Stage 3 is entered usually after several courses and is a gradual resolution of conflict by means of various defence mechanisms. The instructor now knows more or less what to expect and has recovered from several close call situtations. He is now cautious, but not excessively so, and is now a good instructor.

4. Stage of Defence Breakdown

Generally this occurs after several years of instruction, though it may occur after as few as two years. Defence mechanisms, previously effective in dealing with the approach-avoidance conflict, have for one reason or another, broken down. The anxiety is overtly manifested in various ways, such as, prolonging preflight inspections, prolonging safety checks, over-learning of emergency procedures, and over-cautious flying and instructing as well as occasional complaints regarding serviceability of an aircraft, or, of the reliability of that

type of aircraft in general. Other manifestations may include physical diseases, family difficulties, etc. Often there are periods when the instructor drifts back to Stage 3, but these become less frequent and less prolonged. At this point, the pilot's value as an instructor as such may be in doubt, but he may be valuable as a test pilot, a check pilot, or in some supervisory position, or on the staff of a helicopter instructor's school.

The author has noted and recorded illness trends in some pilots over a period of four years. During Phase 2, definite signs were noted in several individuals, particularly during the pre-solo phases of the courses and near the final stages, in some cases. Probably the worst period of the course for manifestations of overt anxiety was during the touchdown autorotation phase of instruction. The following trends were noted:

1. Increased frequency of reporting sick to the flight surgeon.

2. Types of complaints: these usually fell into two categories:

   (a) Stress-related pathology, e.g., recurrent gastritis and peptic ulcer symptoms, recurrent upper respiratory infections, bronchitis.

   (b) Vague illness with no demonstrable pathology, e.g., weakness, fatigue, malaise, weight loss, depression and anxiety.

Increased frequency of visits on sick parade tended to occur during the initial phases of the second or third courses instructed, particularly during the pre-solo stage when the instructors flew four trips per day (i.e., two trips with each student). Those instructors developing obvious pathology usually required grounding for a short period, while those with vague complaints were generally treated successfully with placebos, such as vitamins and supportive psychotherapy. Although the diagnosis of anxiety reaction was suspected, routine investigations were carried out and the pilots were reassured. If the pilot was told that his illness was due to anxiety, he seldom objected and always agreed in retrospect when he was later interviewed. Likewise, if a pilot required grounding, he sometimes feigned disappointment but often appeared inwardly relieved at being withdrawn from the course for a few days.

Two typical cases are presented:

CASE 1 This 35-year-old captain with 1100 hours of CH112 time, mostly in Europe in the reconnaissance role, joined the squadron following the FIS course. During his first course, after three weeks (the highest concentration of PFL'S) he developed "flu" followed by an upper respiratory infection and was grounded. Following his return to flying, one of his students mistakenly lowered collective during a practice hover PFL and the machine sustained minor damage. The pilot then suffered insomnia and developed recurrent upper respiratory infections and bronchitis. He noted insomnia during critical phases of the course, i.e., touchdown autorotations. After the second course, the frequency of illness decreased and gradually tapered off. This illustrates stress-related pathology, which was treated symptomatically at the time, but disappeared of its own accord as experience developed.

CASE 2 This instructor, also in his mid-thirties, reported on sick parade during his second course. His complaints were mainly of fatigue, inability to sleep restfully, and moodiness. The patient was examined and laboratory examinations were performed. No pathology was demonstrated. He was treated with vitamins and had some symptomatic improvement. Several months later, he volunteered the fact that his symptoms were probably due to anxiety.

A preliminary study was initiated by the author which indicated a high stress level among rotary-wing instructors as compared to fixed-wing instructors. A questionnaire designed to give some indication of stress level was passed out to rotary-wing instructors, basic fixed-wing instructors, and a control group. The questionnaire contained 60 questions concerning various aspects of a pilot's life and several questions were fed in which were designed as stress indicators. These delved into such areas as housing satisfaction, drinking habits, job satisfaction, uneasiness towards hazardous aspects of the job, etc. Although a detailed statistical analysis was not performed, one has the impression and may actually conclude that rotary-wing instructors, in general, tend to be less satisfied and happy than fixed-wing instructors. Ninety-two per cent of the rotary-wing instructors felt that their job was the most hazardous as compared to transport flying, maritime flying, fixed-wing instructing, rotary-wing instructing, or fighter flying, whereas only 8% felt that fighter flying was more hazardous. In contrast, only 20% of fixed-wing instructors stated that their role was more hazardous than rotary instructing. Interestingly enough, the rotary-wing students' opinions were equally divided between rotary instruction and fighter flying, though 11% chose fixed-wing instructing as the most hazardous. Those rotary-wing students who responded "fighter" as being more hazardous had less than 500 hours total flying time and it can be assumed that they were "pipeline" pilots. The above observations point out that as one is exposed to more and more rotary-wing flying, the more hazardous it appears to be.

It is well known in the field of experimental psychology that drinking patterns can be directly related to the amount of stress in one's total life situation. Therefore, a second study was undertaken by the author, where candidates were asked to anonymously estimate on a daily basis how much alcohol was consumed during one-week periods. It was found that the estimated consumption was approximately 50% more for rotary-wing instructors than for fixed-wing primary instructors. One might argue that this is due in part to the older age distribution in rotary-wing instructors, but the graph in Figure 8-3 plotting estimated alcohol consumption according to age group belies that argument and shows that if indeed alcohol consumption can be related to stress then rotary-wing instructing is definitely a more stressful occupation than fixed-wing instructing. The graph in Figure 8-4 shows the age distribution of the fixed-wing and rotary-wing instructors examined. The increased amount of drinking recorded by fixed-wing instructors in the older group probably results from frustration at remaining in a Training Command situation at that age.

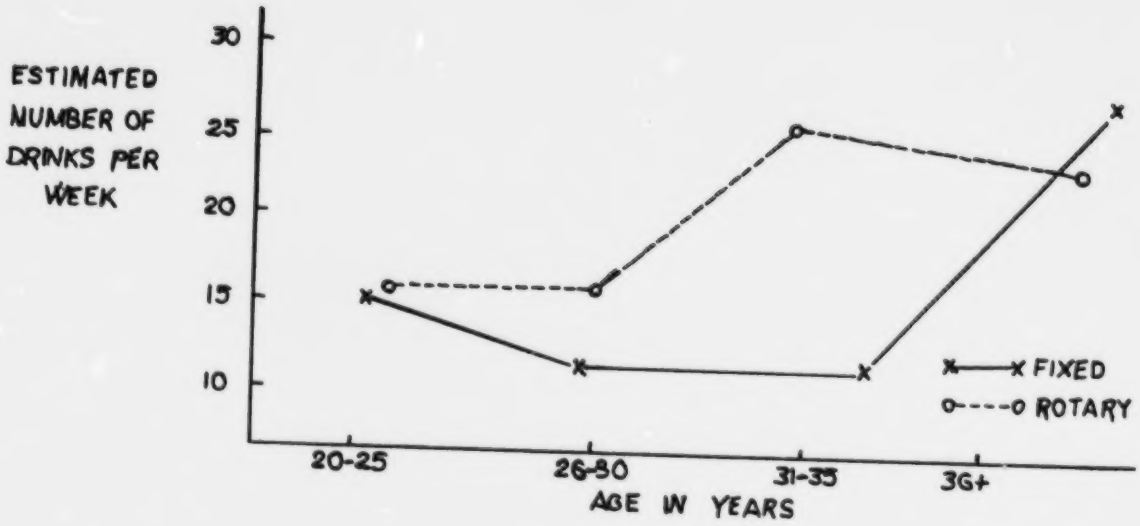

ESTIMATED NUMBER OF DRINKS PER WEEK
30
25
20
15
10
20-25
26-30
31-35
36+
AGE IN YEARS
FIXED
ROTARY

Fig. 8-3

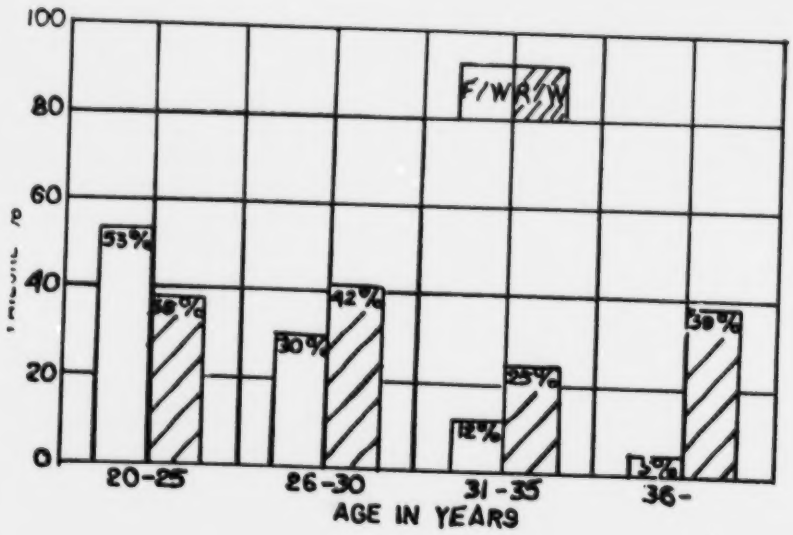

100
80
60
40
20
0
53%
38%
30%
42%
12%
25%
5%
38%
20-25
26-30
31-35
36-
AGE IN YEARS

Fig. 8-4

In addition to the above findings, rotary-wing instructors tended to be less satisfied with their dwellings, career opportunities, etc. Assuming that this dissatisfaction may be partially related to stress and personality changes in the instructors, one may conclude that rotary-wing instructing is a highly stressful occupation. Because of this, the pilot should be monitored carefully by both the flight surgeon and flight commander for signs of fatigue which may alter flying performance, and flying hours should be reduced if necessary. It is also suggested that perhaps a different system for student loading be used. The instructor could handle two students for his first course, but only one student for the second course, to decrease the anxiety load during this period, as the second course seems to be critical, in terms of anxiety development. Two pre-solo students constitute a heavy load for any instructor.

Flying Decompensation Syndrome and Fear of Flying

As pointed out previously, fear of flying and flying decompensation syndrome is not uncommon in helicopter pilots, particularly helicopter instructors. It is not necessarily confined only to helicopter pilots and may be found in other areas of the aviation environment where the rapidity of onset appears to be related somewhat to risk.

Since flying is not natural to man it should not be considered unnatural or abnormal that man fears to fly (Ref. 46). In order for man to fly he must go through a process of adaptation where balance between motivation and fears is obtained. Some of the basic fears which man has is of mutilation and a very early fear of height.

Anxiety must be controlled and flight accepted. This is termed the flying compensation syndrome by Llosa-Rojas and was defined as all of the required behaviour which an individual has to learn in order to actuate himself against the instinct of self-preservation, compensating for it in such a way as to control anxiety. This is accomplished through technology, training and effective and intellectual acceptance of allowing unnatural activities to be incorporated as normal ones.

A state of compensation may go on to a disequilibrium towards instinctive self-preservation. This in turn goes on to a reaction to decompensation which is considered abnormal but natural and non-pathologic. This is termed the flying decompensation syndrome and is defined as a disequilibrium of the state of compensation in favour of the instinctive component and caused by external stress, whereas the fear that is felt corresponds to a real risk.

Flying decompensation syndrome may be primary or secondary. In the first instance a primary reaction occurs in individuals who have not experienced flight but who have intellectually accepted the idea of flight. These individuals experience a fear reaction during the actual flight. The secondary flying decompensation syndrome occurs in individuals who had previously become comfortably adjusted to actual flight conditions. They face some severe environmental stress which produces a decompensation resulting in fear of flying. In fact this may be a reduction in defence mechanisms and may correspond to actually greater insight into the hazards associated with flying.

There are differences between flying decompensation syndrome and phobic neurosis.

These are basically as follows:

1. Flying decompensation syndrome occurs in individuals with minimal or no neurotic predisposition, while phobic neurosis occurs in anxious personalities.

2. The flying decompensation syndrome premorbidly is characterized by the flying compensation syndrome, while the phobic neurosis is characterized by defence mechanisms of displacement and symbolization.

3. In the flying decompensation syndrome the individual reacts to a real risk, whereas in a phobic neurosis the individual reacts to a situation with no real danger.

4. In the flying decompensation syndrome the individual is well aware of the risk which determines his suffering, while in the phobic neurosis the individual recognizes that his fear is absurd but is unable to control himself in the presence of the feared object or situation.

5. In the flying decompensation syndrome the reaction is abnormal but not indictative of psycho pathology, while in the phobic neurosis the reaction does indicate psycho pathology.

6. A person with the flying decompensation syndrome should not be considered as ill, while the person with the phobic neurosis is considered ill and requires treatment.

According to this paper the spectrum of fear flying is made up of the following five steps:

1. Natural instinctive reaction.

2. Primary flying decompensation syndrome.

3. Secondary flying decompensation syndrome.

4. Phobic neurosis.

5. Psychosis with fear of flying.

The author, in his experience with primary care of flight crew and in accident investigation, has observed many cases of flying decompensation syndrome and fear of flying. This usually resulted from the breakdown of defence mechanisms as a result of exposure to environmental stresses, and the stresses of accidents occurring in colleagues where in later years of the pilot's life it was more difficult to rationalize the event and it seemed that the pilots developed more insight into the actual risks associated with flying. The final outcome of fear of flying took five basic routes.

1. Development of Psychosomatic Illness

Stress related illnesses such as hypertension, peptic ulcers and the onset of diabetes tended to occur in these individuals. In addition, as discussed before, drinking patterns changed and there was a higher intake of alcohol. These symptoms were often related to stressful types of flying, for example, touchdown autorotation training, and tended to disappear when the pilot was removed from these situations.

Non-specific illnesses such as malaise and upper respiratory infections were frequent in these individuals as discussed previously.

2. Withdrawal from Flying

Many pilots who began to suffer from flying decompensation syndrome retired from flying, giving vague excuses such as not liking the long hours or working in isolation. In the civilian helicopter pilot population retirement or withdrawal from flying tends to occur at a relatively early age.

3. Obsessive Compulsive Neurosis

Some pilots when entering the first stages of flying decompensation syndrome tended to become overly obsessive and compulsive about certain aspects of safety. In its extreme this can result in a condition of tunnel vision where the pilot is no longer able to see the forest for the trees. For example, I have observed a pilot go out and preflight a helicopter three times and then do something absolutely absurd like a take off into freezing rain. Obviously obsessive compulsive neurosis is a dangerous phenomenon in an operational environment.

Sometimes following accidents, pilots become over-concerned about safety. For example, following an accident in the military where the cause was not initially determined a poster was put out regarding the particular type of machine in use. The poster showed a photograph of the machine and underneath there was stated that this machine had over 10 000 hours of air frame time without accident. Instead of achieving its purpose of making pilots more confident in the machine, the poster actually tended to make them a little more anxious about the helicopter.

4. Counter-phobic Defence Mechanism

Not uncommonly, pilots when entering flying decompensation syndrome or fear of flying syndrome, develop a counter-phobic defence mechanism. Since pilots viewing their task as very macho believe they should maintain a macho image, and losing their nerve does not particularly suit this type of image. Pilots, therefore, subconsciously or consciously put themselves in situations which are anxiety provoking. For example, some pilots, if they develop anxiety about weather, will sometimes push the weather to test their own nerve. This may explain the accident type of situation where a very experienced pilot does something which would not normally be attributed to someone with that amount of experience.

5. Some Pilots May Seek Therapy

It is tragic to have a resource such as a pilot lost when therapy applied by a trained and experienced individual may alleviate the problem and allow the pilot to return to flying without undue anxiety or neurosis. The Royal Air Force, for example, has a program where psychiatrists become directly involved with the pilot in taking him through, first of all by interview, his anxiety provoking situations and then eventually flying with the pilot in the same type of situation. The success has been remarkable in this program.

One danger which occurs occasionally in pilots who are passing from a sort of "hot pilot" stage into an "airplane driver" stage is that they may view themselves as losing their nerve and develop excessive anxiety over this apparent decline. Usually a pilot, when experiencing these feelings, will get over them if he continues to fly. Sometimes it requires mental effort to force oneself out to the flight line and into a machine but, on returning to the normal flying environment, the anxieties rapidly disappear.

Personality Factors - Civilian Helicopter Pilots

In 1980 a study was commenced using PROBE and PRIME tests developed by Dr. David Vinson of Assessment Systems Inc. in Houston to test rotary and fixed-wing pilots and ATC's with the idea of evaluating the potential of the tests as a possible selection tool. During 1980 approximately 80 fixed-wing students, 25 rotary-wing students and 60 Air Traffic Controllers were tested.

It became apparent almost immediately that there was a difference between rotary-wing students and the other pilots tested. It is possible, following testing, to produce a visual analogue model called a Starr Plot of five elements of personality and mental function. These include rate of learning, rate of information processing, ability to evaluate self-performance, conformity and productivity. It was noted that helicopter pilots tended to be low in conformity and productivity. The pilots expressed a lack of confidence, with a need to control others. This type of personality may be easily influenced and a person of this type can be "egged" on into an accident situation. In addition, the pilots had a very high achievement need.

Because of the difference involved in this group of pilots it was decided to interview them personally. A structured interview situation was arranged so that the following areas were explored: 1) past history; 2) motivating factors, i.e., what the pilot thought he would get out of flying; 3) what the pilot actually got out of flying; 4) reaction to accidents.

All of the pilots except two showed a basic pattern of wishing to be independent and away from the confines and restraints placed upon them by Air Traffic Control and other agencies. They all tended to be self-starters and all except three had been involved in starting up their own small businesses, such as swimming pool excavation, etc. Another interesting feature in this group was very strong family support towards their flying activities, particularly from their father. All of the group interviewed had a close relationship with their fathers at an early age.

The two exceptions to the rule were both foreign students who had scored very high in all phases of testing, including conformity. These two individuals had paid their way over to Canada and wished to complete their training here and then return to their home country, where they would be involved in flying to off-shore oil rigs in an IFR type of operation. In this respect they fitted perfectly into the profile expressed by the Starr Plot, particularly in terms of conformity and productivity. These two individuals also scored highest on rate of learning and rate of information processing, and did best in the written exams and helicopter test rides.

There appeared to be a direct relationship between scores in rate of learning and mental time-sharing and written examination test results.

All of the pilots tested scored fairly well in terms of ability to self-evaluate and this was borne out by the careers which they had chosen and which matched very closely their conformity and productivity wishes. The one area in which all of the pilots were unrealistic was with regard to their career potentials in helicopter flying. They were all extremely confident that they would be hired soon after graduation and that their multi-thousand dollar investment would pay off rapidly, this despite the fact that at the time there was a glut of helicopter pilots on the market and some schools were claiming that only about 50% of their graduates were actually hired.

Work with these tests is continuing and it is hoped that they will not only continue to provide a remarkable insight into an individual's mental function but also be of some predictive validity in terms of success or failure in flying. In addition, it may be possible to identify areas of specific weakness which may become apparent while training and thereby giving the instructor some forewarning as to which areas of training should be emphasized.

CHAPTER IX

"Even more than the sea is the air unforgiving of man's errors."

EMERGENCIES IN HELICOPTERS

It has been stated many times since the history of flight began that the air, even to a greater extent than the sea, is not forgiving of the frailties of man and machine. This is particularly so with helicopters, as any type of emergency can lead to disaster if the appropriate actions are not taken, and in many instances even when the appropriate actions are taken. Emergencies in helicopters fall into two main categories: (1) those requiring precautionary landings, and (2) those requiring emergency landings. Obviously, those in the second category are of a more serious nature and result in the greatest number of accidents. The most serious emergencies in this category are those involving loss or damage to a major flight component and include:

1. loss of main rotor;
2. transmission failure;
3. engine failure;
4. clutch failure;
5. loss of anti-torque rotor;
6. loss of tail rotor pitch control;
7. fires.

Loss of the main rotor or a transmission failure would result in an uncontrolled descent, whereas partial control to a safe touchdown may be attained in the other emergencies.

One of the most dreaded emergencies in any type of aircraft is fire. Fires in helicopters may be differentiated into engine fires, fuselage fires, or electrical fires. Remedial action is simplest in the case of electrical fires as it entails usually just turning off the battery and master switches. One type of electrical fire, (or in the worst case, explosion) which occurs in modern aircraft is a "thermal runaway" of the nickel-cadmium batteries. During this process, tremendous temperatures may be reached - high enough to melt aluminum fire walls and the battery may actually explode. Engine fires and fuselage fires may or may not have disastrous consequences, depending upon their location, size, etc.

To provide an early indication of impending transmission failure, transmission oil pressure and oil temperature warning lights are incorporated into the lubrication system. Chip detectors, which warn of metallic particles in the oil, may also be incorporated into the transmission, and in many cases, the engine as well. Should a transmission or chip detector warning light come on, the corrective action is to descend under power as quickly as possible, and land.

In the pioneer days of helicopter flying, two philosophies developed regarding cruising altitudes. Some pilots preferred to fly low in case of a transmission failure, while others preferred to fly at higher altitudes in case of an engine failure. In modern times, either type of failure is relatively rare, but exponents of both philosophies are extant.

Failure of the tail rotor results in uncontrolled yaw opposite to the direction of the main rotor rotation. The only action available to the pilot is immediate autorotation. On the other hand, some control is retained with failure of the tail rotor pitch linkages, and the machine can usually be flown to a safe landing under power, the yaw being controlled with applications of throttle and collective pitch.

1. Standard Autorotation

   To enter a standard autorotation, the collective pitch level is lowered immediately, pedal is applied to counteract the yaw, and the airspeed is reduced to that appropriate for the type of helicopter. For example, in the Hiller, the autorotative airspeed is 45 knots. Approximately 75 to 100 feet from the ground, a flare is initiated in order to reduce airspeed, reduce rate of descent, and build up rotor r.p.m. Just before touchdown, the aircraft is levelled and collective is applied to cushion the landing.

2. Constant Attitude Autorotation

   The autorotation is entered in the same manner, but the autorotative speed is reduced (e.g., in the Hiller to 35 knots) and a level altitude is maintained to the point of touchdown. In other words, the pilot does not flare. This is the most commonly used at night where it may be difficult to see the ground and other obstacles and accurately estimate the height at where a flare should be initiated.

3. 180 Degree Turning Autorotation

   This type of autorotation is employed if the helicopter is travelling downwind at the time of the engine failure. A standard autorotation is entered and the machine is immediately banked to the left or right in order to complete a 180 degree turn before flare. During the turn, the autorotative force is increased due to the increased angle of the relative wind and therefore some collective must be held during the turn.

4. 360 Degree Turning Autorotation

   If the desired touchdown area is directly beneath the machine at the time of failure, a 360 degree turning autorotation may be used to reach the appropriate touchdown site. In reciprocating type helicopters, at least 1000 feet of altitude is required in order to accomplish the 360 degree turn.

5. "Zero Speed" Autorotation

   Again, if the intended area of touchdown is directly beneath the helicopter, and the machine is flying into a relatively strong headwind, a "zero speed"

autorotation may be used. In order to accomplish this, the autorotation is entered by lowering collective, applying pedal opposite to the yaw, and holding the nose of the helicopter up until the airspeed reads zero. The helicopter then drifts backwards over the touchdown area. With at least 500 feet of altitude remaining, the nose is lowered in order to increase the airspeed to the appropriate autorotative speed and the remainder of the autorotation is standard.

6. Extended Range Autorotation

In most helicopters the distance of the glide to touchdown can be extended by increasing the autorotative speed and holding enough collective to maintain a minimum rotor r.p.m. As the point of intended touchdown is approached, a gradual flare is introduced to build up rotor r.p.m. and decrease airspeed. The final phase of the touchdown is standard.

7. Speed Reduction Autorotation

In the (OH58-A) Kiowa, which is equipped with high-inertia blades, it is possible to actually gain altitude as speed is reduced, if the engine failure occurs at cruise airspeed.

To aid in the understanding of emergencies with which a helicopter pilot must be able to cope, and how he must cope with them, an emergency checklist from the (OH58-A) Kiowa is presented as an example, after the following comment.

The checklist can be roughly divided into non-critical emergencies and critical emergencies. The pilot must have a good working knowledge of how to handle the non-critical emergencies, but because of their nature he may have time to refer to the checklist. However, procedures for critical emergencies must be memorized as a response to the situation must be immediate and accurate. It must be emphasized at this time that this is a relatively old checklist and many changes will likely have been incorporated by the time this writing is published.

NON-CRITICAL EMERGENCIES

YOU HAVE SUFFICIENT TIME TO CONSULT

CHECKLIST AND ADVISE AUTHORITY

CAUTION PANEL

FUEL SYSTEM

FUEL BOOST

- o Fuel boost pump inoperative:
  - Fuel Pump Circuit Breaker - Reset
- o If light still illuminated:
  - Fuel Boost Switch - Off

DO NOT ATTEMPT START

AVOID FLIGHT ABOVE 10 000 FEET

20 MIN. FUEL

- o Enough fuel remaining for 20 min. of flight at cruise power
- o 65 to 100 lbs. or less fuel remaining

LAND AS SOON AS PRACTICABLE

FUEL FILTER

- o Filter clogged; unfiltered fuel being delivered to engine

LAND AS SOON AS PRACTICABLE

OIL SYSTEM

ENG. OIL BYPASS

- o Oil level low and engine oil bypassing cooler if engine oil bypass switch selected to AUTO:
  - Engine Oil Bypass Switch - AUTO

LAND AS SOON AS PRACTICABLE

ELECTRICAL SYSTEM

INST. INVERTER

o AC inverter has failed:
- Inverter Switch - OFF
- AC Fail Relay Circuit Breaker - Reset
- Inverter Switch - ON

If instrument caution light still illuminated:
- Inverter Switch - OFF

VRF FLIGHT MAY BE CONTINUED

DC GENERATOR

o DC generator has failed:
- Generator Switch - Recycle; if power not restored - OFF
- Generator Field Circuit Breaker - Check
- Generator Switch - ON

If power not restored:
- Generator Switch - OFF
- Electrical Equipment - OFF (except as required)

LAND AS SOON AS PRACTICABLE

HYDRAULIC SYSTEM

HYD. PRESS

o Hydraulic pressure low:

- Adjust airspeed for best control (70-80 Kt)
- Hydraulic Boost Switch - ON
- Hydraulic Boost Circuit Breaker - Out, if hydraulic pressure not regained
- In
- Hydraulic Boost Switch - Recycle; if hydraulic pressure not regained

LAND AS SOON AS PRACTICABLE

IFF SYSTEM

IFF

- The IFF System is inoperative

CRITICAL EMERGENCIES

IMMEDIATE ACTION REQUIRED

CAUTION PANEL

ENG CHIP DET
XMSN CHIP DET
T/R CHIP DET

- Foreign metal particles in system indicated; possible system failure impending

INITIATE A RAPID POWER-ON DESCENT AND LAND AS SOON AS PRACTICABLE

WARNING PANEL

ENGINE OUT

- Engine N speed below 55% (+3); engine has failed or is failing (normally accompanied by "engine out" audio tone)

INITIATE ENGINE FAILURE PROCEDURE

XMSN

OIL PRESS

- Oil pressure less than 30 PSI or more than 80 PSI

INITIATE A RAPID POWER-ON DESCENT AND LAND AS SOON AS PRACTICABLE

XMSN

OIL HOT

- Transmission dangerously hot:

INITIATE A RAPID POWER-ON DESCENT AND LAND AS SOON AS PRACTICABLE

EMERGENCY ENGINE SHUT-DOWN

Throttle	- Close
Fuel Valve Handle	- Close
Battery Switch	- Off

ENGINE FAILURE - HOVER/TAXI

Collective	- Adjust to cushion landing

After Landing:

- Complete Emergency Engine Shutdown

ENGINE FAILURE - ALL ALTITUDES

Collective	- Adjust as necessary to maintain rotor r.p.m. (330-390)
Throttle	- Close

Carry out autorotative landing

Prior to landing, as time permits:

- Complete Emergency Engine Shutdown

NOTE

Maximum recommended airspeed for autorotative flight is 100kt.

ENGINE RESTART DURING FLIGHT

Establish autorotative glide

If altitude sufficient to attempt, restart and engine failure was not due to mechanical malfunction:

- Throttle	- Close to idle stop
- Start Button	- Depress & release at 58-62% N_1
- Throttle	- Open slowly to full open (if restart successful)
- TOT Gauge	- Monitor

FIRE

ENGINE FIRE DURING START - INTERNAL

Start Button - Keep depressed

Throttle - Close

Fuel Valve Handle - Close

When TOT decreases to normal:

- Complete normal shutdown and record Hot Start

ENGINE FIRE DURING START - EXTERNAL

COMPLETE EMERGENCY ENGINE SHUTDOWN

Exit aircraft and fight fire, using aircraft fire extinguisher as necessary.

ENGINE FIRE DURING FLIGHT

Establish Autorotative Glide

Complete Emergency Engine Shutdown

FUSELAGE FIRE

Airspeed - Reduce to minimum

Generator Switch - Off

Battery Switch - Off

LAND AS SOON AS PRACTICABLE

Shutdown and fight the fire

ELECTRICAL FIRE

Generator Switch - Off

Battery Switch - Off

LAND AS SOON AS PRACTICABLE

Investigate

SMOKE ELIMINATION

Cabin Heat - Off

Vent - On

Defog and Vent Switch - On

Cabin Door Vents - Open

LAND AS SOON AS PRACTICABLE

FUEL SYSTEM

OVERSPEED GOVERNOR FAILURE

Collective Pitch - Increase or maintain rotor r.p.m. below 390

Throttle and Collective Pitch - Adjust to maintain 100% N (if possible) or to idle stop

LAND AS SOON AS PRACTICABLE WITH POWER OR ENTER AUTOROTATION

UNDERSPEED GOVERNOR FAILURE

Collective Pitch - Reduce to maintain rotor r.p..m. in green arc

Throttle - Maintain or reduce to idle stop as necessary

LAND AS SOON AS PRACTICABLE WITH POWER, OR ENTER AUTOROTATION

N_2 POWER SURGING

Governor/r.p.m. Switch - Increase to maximum

Throttle	-	Reduce to 100% N, or idle stop as necessary

LAND AS SOON AS PRACTICABLE WITH POWER OR ENTER AUTOROTATION

COMPRESSOR SWITCH

COMPRESSOR STALL

Power	-	Reduce
Engine De-Ice Switch	-	Off
Heater Switch	-	Off

If procedure does not eliminate problem:

- Land and investigate

LANDING AND DITCHING

FORCED LANDING IN TREES

Proceed as per ENGINE FAILURE - ALL ALTITUDES

Groundspeed	-	Reduce to zero at treetop level
Collective Pitch	-	Increase (for minimum descent as aircraft settles into trees)

DITCHING - POWER OFF

Proceed as per ENGINE FAILURE - ALL ALTITUDES

Alert Passengers

Doors	-	Jettison
Groundspeed	-	Reduce to zero before contact with surface
Collective Pitch	-	Increase (to minimize sink rate)

When rotor stopped:

- Release Harness
- Abandon Aircraft

DITCHING - POWER ON

Alert Passengers

At a low hover:

- Doors - Jettison
- Passengers and Crew - Order to abandon

Taxi well clear of crew and passengers

Generator and Battery Switch - Off

Throttle - Close

Collective Pitch - Increase to minimize sink rate at water surface

When rotor stopped:

- Release Harness
- Abandon Aircraft

ANTI-TORQUE SYSTEM

LOSS OF TAIL-ROTOR CONTROL

DO NOT INITIATE NORMAL EMERGENCY PROCEDURE UNTIL CONTROLLABILITY IS ESTABLISHED

LEFT PEDAL LOCKED FORWARD OF NEUTRAL

To achieve manual throttle control:

- Governor/r.p.m. Switch - Increase to maximum

- Throttle	-	Reduce to 101% N_2

Gradually reduce airspeed during approach to arrive at a point about two feet above intended touchdown area as translational lift is lost

Throttle/Collective	-	Adjust to align aircraft with intended landing direction
Cyclic	-	Apply in direction of turn after landing

RIGHT PEDAL LOCKED FORWARD OF NEUTRAL

To achieve manual throttle control:

- Governor/r.p.m. Switch	-	Increase to maximum
- Throttle	-	Adjust to 103% N_2

Select approach path which will put the wind on the left at 90 degrees to achieve best keel effect. To further enhance this effect displace cyclic into wind (i.e., cross control). Gradually reduce airspeed during approach to arrive at intended point of landing, maintaining translational lift.

Throttle/Collective	-	Adjust to align aircraft with intended landing direction
Cyclic	-	Apply in direction of turn after landing

LOSS OF PITCH-CHANGE CONTROL LINKAGE

Follow the procedures as outlined above depending on yaw change experienced.

HOVER

Throttle	-	Close
Collective	-	Adjust to cushion landing

After landing:

- Fuel Valve Handle - Off
- Battery Switch - Off

FLIGHT

Establish autorotative glide and, if possible, attain 60 kt. Check controllability by gentle applications of throttle and/or collective pitch, and if controllable, resume restricted power flight.

If adverse yaw encountered:

- Resume autorotative flight

If time permits:

- Battery Switch - Off

When landing area assured:

- Throttle
- Carry out autorotative landing - Close

Emergency Escape from Helicopters

In the present state of the art, a pilot must fly the helicopter to termination of the emergency - there is no means of escape. Because of the design and configuration of helicopters, many difficulties have been encountered in trying to provide an adequate and effective means of escape should an emergency arise. Research into escape systems is currently being done in several centres and three main concepts have evolved:

1. Horizontal Extraction Seats

   With this system, rockets extract the pilot from the craft horizontally at first to avoid the rotor, and then upwards to clear the aircraft.

2. Breakaway Rotor with Ejection Seats

   With this system, the rotors are jettisoned by means of explosive charge and the pilot then employs a standard jet-aircraft type ejection seat to escape the aircraft. It can readily be seen that a fairly substantial height must be reached before the ejection sequence is initiated. In addition, the ejection seats themselves must have a greater than zero-zero capability. That is, ejection to effective parachute deployment must occur even with a substantial sink rate.

3. Breakaway Crew Sections

With this type of system, an explosive charge removes the main rotor and then further explosions detach the crew capsule from the remainder of the fuselage. The capsule then descends on parachutes.

To this date, no practical system is in use in helicopters.

Much effort is being directed by several agencies towards improving the likelihood of survival in helicopter accidents and this will be discussed in future chapters.

CHAPTER X

"To see the results of the forces normally used in the creation of flight misdirected to a frenzy of destruction is frightening and bewildering."

HELICOPTER ACCIDENT INVESTIGATION

To say the least, investigation of a helicopter wreckage can be bewildering. Although many of the rules that apply to fixed-wing accident investigation also apply to helicopters, there are many exceptions. For example, in mid-air breakups, the wreckage distribution may not indicate the flight path before disintegration because of the wide random scattering of parts, particularly rotor parts. Two of the most striking features of helicopter accidents are the suddenness of the event, and the large amount of damage which can occur in what may seem to be a trivial mishap. This is usually due to the fact that the rotors are moving at high velocity and the machine may literally beat itself to death as it thrashes about on the ground.

Photo 10-1

In the investigation of any accident, perhaps the most important fundamental concept is the concept of combined factors. It is extremely rare, when using modern techniques and philosophies, that a single cause can be found for any accident. Therefore, it is important that the investigator take into consideration all aspects of the accident, so that the basic elements of the aerospace system, i.e., machine, environment and man, may be considered individually and as an integrated formula. Most accident investigation teams are divided into operational, technical, and medical members. Although the operational and technical members pursue their particular phase of the investigation in great detail, it is the duty of the human factors investigator to find out as much as he can about these other aspects, so that he may integrate his investigation to form a complete and reasonable picture. For this reason, the author is including some aspects of the operational and technical investigation procedures in this section. It is important at this point to realize that this chapter and the following chapters should not be construed as being a complete reference regarding helicopter accident investigation, but should be used as merely an adjunct to the human factors investigation.

Accident investigators, ideally, are supposed to arrive at the scene of an accident possessing no preconceived ideas or theories which may lead them down the wrong track. This may present a problem to the medical investigator, who has been trained to construct a differential diagnosis and pursue each facet until it is proven correct or incorrect and arrive at a final diagnosis by a process of elimination. This system has limited use at the site of a helicopter accident, or for that matter, any accident, as much time and effort may be wasted by sidetracking to pet theories, etc.

The following cautions should always be kept in mind:

1. Beware of preconceived ideas.

2. Record what is seen and then attempt analysis. Do not think up a theory and set out to prove it.

3. Keep the investigation moving. Do not bog down with minor unknowns.

4. Do not be afraid to ask questions.

5. Do not be afraid to delegate work. There are always people around who are willing to help.

The format for a human factors investigator's accident report must, of course, fit the requirements of the agency for whom the investigation is being performed. However, the author has found the following format to be of use in not only organizing his thoughts during an investigation, but also in designing the final report:

(a) Introduction

The introduction is usually a simple preamble including such information as weather conditions at the time of the accident, purpose of the flight, names of the passengers and crew, etc.

(b) Crash Sequence

The final flight path and crash kinematics are detailed in this section. Much of the information can be gleaned from the operational and technical investigators, but it also behooves the human factors investigator to make his own assessment at the crash scene. This section also includes a description of the wreckage distribution, location, and disposition of the victim, etc.

(c) Autopsy

A detailed description of injury patterns is presented in this section. In addition, an attempt is made to correlate injuries with the probable crash kinematics, cockpit construction, etc. The aviation autopsy will be discussed in more detail later.

(d) Biochemical Results

This includes in tabulated form the results of blood and tissue alcohol analysis, carboxyhemoglobin, lactate profile, and other toxicological results which may be available.

(e) Pilot History

A description of the pilot's training and past experience, as well as his occupational and social environment are included in this part of the report. In other words, this is a form of psychological post mortem report. In addition, a detailed history of the pilot's activities in the 48 hours preceding the crash is important, especially when considering such factors as fatigue, illness, hypoglycemia, etc.

(f) Employment History

In general, this is a description of the pilot's working conditions. Much of this information is obtainable from the operational member of the investigation team, but it is important for the investigator to peruse work records, and evaluate employer-employee relationships, etc.

(g) Conclusions

This includes an evaluation of the emergency response, human factors which may have had an effect on the accident event, and the causes of death.

(h) Survivability

The survivability factors involved in the accident are investigated and reported by the human factors investigator. The investigator must be able to tie together the crash kinematics, injury patterns, and technical details, into a final evaluation of survivability. This will be discussed in further detail in Chapter X.

(i) Safety Equipment

An evaluation of safety equipment such as crash helmets, restraint systems, fire-resistant clothing, etc. is made.

(j) Recommendations

Recommendations regarding remedial action which may be taken to prevent further accidents, resulting from the investigation, or which may improve survivability in future accidents are made in this section.

Perhaps the major problem confronting an investigator is rapid and accurate data acquisition. Often, the accident investigator does not have what he considers to be adequate time to spend at the scene of an accident, due to pressures such as workload, or the pressure from local authorities or organizations to conduct a rapid investigation and arrive at a solution to the problem. For these reasons, discussion of equipment which can assist the investigator in acquiring data is warranted at this point. The author, in addition to routine field equipment such as seasonal clothing, rubber boots, axes and rations, etc., suggests the following equipment be included in the human factors investigator's inventory:

1. Photographic

(a) 1 35 mm. single-lens reflex camera with a standard 50 or 55 mm. lens, plus a 35 mm. wide-angle lens. The camera should be equipped with a behind-the-lens light meter for exposure accuracy. Automatic exposure cameras are not recommended, unless the automatic shutter has a manual over-ride. In addition, an electronic flash unit should be included for photographing in minimal light conditions. Ideally, this should be an automatic flash which obviates the necessity for making camera adjustments each time a photograph from a different distance is required.

(b) Polaroid SX-70

The Polaroid camera is ideal as an adjunct to a 35 mm. camera, as instant prints are often desirable. The newest Polaroid models such as the SX-70 are ideal as they have a single-lens reflex capability which eliminates paralax errors and it is also not necessary to time the developing process.

(c) Pocket Camera

A small, cheap pocket camera is useful when it may be difficult to transport the larger cameras. However, they have a limitation in that the negative format is small and much clarity is lost in the printing process, or when a slide is projected, due to graininess of the film, etc.

(d) Tripod

A tripod for the 35 mm. camera should be carried in case it is necessary to take time exposures, or "paint in" a picture at night.

(e) Film

The author heartily recommends that 35 mm. high-speed colour slide film, as well as coloured Polaroid film, be used for accident photography. It is usually much easier to pick out detail when colour contrasts as well as shade contrasts, are available.

2. Tape Recorder

A running description of the accident site should be recorded on a small pocket tape recorder during the investigation. In addition, witnesses' statements can be recorded with this device.

3. Tape Measure

4. Compass

5. Tools

(a) A good hunting knife

(b) Hatchet

(c) Screw drivers and pliers

(d) Scalpels

(e) Scissors, hemostats, tape, small plastic bags, etc.

6. Protective equipment e.g., respirator for use when toxic agents such as insecticides, extinguishers, etc. are present.

7. Inclinometer

8. Pocket Calculator

9. Mathematical Tables (e.g., Knott's 4 Figure Tables)

10. Range-finder (a "nice-to-have" item)

11. A small model helicopter

12. Magnifying lenses

Accident Photography

Probably the most valuable tool to the accident investigator is the camera. It is essential that the investigator not be afraid to use up film, as one can never take enough pictures, and the tragedy of not possessing enough information, should a new

idea occur, must be avoided. In addition, the investigator should either take his own pictures, or ensure that the photographer on the job is reliable and has training and experience which will enable him to fulfil the requirements. It is very important to commence taking pictures early during the course of an investigation before the wreckage is disturbed, and marks on the ground, etc., are obliterated. It is often very difficult to know just where to begin upon arrival at an accident scene, and the author therefore uses a systematized approach to photography and usually begins taking photographs as soon as possible. A system such as the rule of 5 P's can be used. These include:

P - paths
P - points
P - pathology
P - parts
P - particulars

These photographs can be taken as follows:

(a) Paths

The first photographs are taken looking forward and rearward along the path of wreckage distribution and for final flight paths. They should include, if possible, such details as hills, trees, wires, and other obstacles in the background. For this reason, it is best to use a wide-angle lens for these photographs. Aerial photographs should be included, if possible.

(b) Points

Eight photos are then taken, using the ordinal and cardinal points of the compass as a reference. Pictures are taken from the north, south, east and west, from a great enough distance to include all of the major portions of the wreckage. The photographs taken from northeast, northwest, southeast, and southwest, are taken closer in to the wreckage, if desirable. This system can, of course, be modified to fit the particular requirements of the accident-scene situation.

(c) Pathology

If victims of a fatal accident are still located in the wreckage, photographs should be taken before and after removal. Polaroid photographs are of great assistance here as they will help the pathologist correlate the injury patterns to the wreckage during the autopsy.

(d) Parts

Various small parts which may be scattered away from the main wreckage distribution should now be photographed. These would include such items as rotors, tail rotors, and other equipment.

(e) Particulars

Particular items of great interest such as scratch marks, dents, wire marks, etc., should all be photographed. In addition, these marks should be re-photographed once the wreckage is roughly reconstructed.

Often a "panorama" may be desirable. To accomplish this, multiple photos from a fixed viewpoint are spliced together or overlapped to form a panoramic view.

A running tape description with a brief commentary on each photograph, e.g., position from where the photograph was taken, details which should be noted in the photograph, etc., should be made while the photography is in progress.

It is very important that the investigator know as much as he can about the operation and limitations of each of the cameras in his inventory. For this reason, it is a good idea to either take a study course which is available at many camera clubs, or read further on the subject of photography.

Each of the cameras has a particular function in photographing around an accident scene and this should be discussed in some detail. Perhaps the most versatile of the cameras in one's inventory is the 35 mm. single lens reflex camera. A good camera with behind the lens metering is probably one of the most foolproof pieces of equipment available to the investigator, if the limitations and problems are understood. With a single lens reflex camera one is able to visualize exactly what the film is going to record and there is no problem with parallax, etc. In addition, accessory lenses for either telephoto or wide angle viewing and extension tubes or bellows for macro photographs may be employed without making any corrections for parallax or exposure, provided that the camera is equipped with behind the lens metering.

Although seeming to be an ideal camera for all situations, the Polaroid camera does have its limitations, although many of these have been obviated with the SX-70. Prints from a Polaroid camera tend to be more washed out with less contrast than with, say, a good 35 mm. slide film. In addition, with the older types of Polaroid cameras, much time was wasted timing the development of the photograph. This becomes unnecessary with the SX-70.

The Polaroid camera, however, has many advantages, and should be carried to an accident scene whenever possible. First of all, if the correct exposure, etc. is not used or the required detail is not visible in a photograph, this becomes immediately obvious, and a repeat photograph can be taken. Secondly, it is often handy to have photographs of the accident site available later on. For example, in the evening when the team has gathered around for a discussion, theories can often be supported or discarded by simply looking at a good set of photographs. Thirdly, the Polaroid photograph is useful during the performance of an autopsy. The pathologist is allowed to view the circumstances of the accident, which not only improves public relations but also enables and encourages him to search for detail while performing the autopsy.

It must be remembered that a camera sees exactly what is there, and, unlike the investigator's eyes, is not influenced by a brain which has a tendency to interpret.

For example, an "available light" photograph taken under tungsten bulbs will have a red cast as compared to the colours which one "sees" when viewing the same scene with the naked eye.

If one is photographing an object against a bright background, the light meter records the average light arriving in the viewfinder and the picture may turn out to be a silhouette. To avoid this, it is necessary to move in close to the object first, in order to take an exposure and adjust the setting on the camera.

Incidentally, one very important but little known trick which can be used for photographing at night is the technique of "painting in". In order to do this, the camera is set up on a tripod and the lens is held open at a setting appropriate to the distance from the wreckage. The photographer then walks around with his electronic flash, and using repeated flashes, paints the scene with light. The final result is a picture nearly as perfect as if it had been taken in daylight. This technique has many other applications aside from aircraft accident photography and the reader is urged to try it at some time.

Although the author recommends using a high speed film and an electronic flash in marginal light conditions, in some cases it may be desirable to have the film "pushed". To accomplish this the film is exposed at a higher ASA, usually a multiple of the original ASA rating, and the film processor is instructed to develop it at the higher ASA value. He simply develops it with a hotter than normal bath and for a longer than normal time. Although the final product is somewhat grainier, little is sacrified by way of resolution. Obviously, it is essential that the entire roll be exposed in the same ASA setting.

Witnesses

Witnesses, depending upon their reliability, may or may not be a useful adjunct to an accident investigation. At any rate, it is important that they be interviewed. Many fine papers have been written on interviewing techniques and it is not the purpose of this publication to elaborate on these. However, there are several basic rules which one should always bear in mind when interviewing witnesses:

1. Interview immediately, or as soon as possible.

2. Keep the witnesses segregated.

The first two rules are extremely important because if a witness is allowed too much time to think about what he saw, he will tend to subconsciously arrive at a plausible explanation for the often tragic events by confabulation. In other words, if he only bore witness to segments of the total accident sequence, he will attempt sub-consciously to fill in the gaps to form a continuum. In addition, witnesses have a tendency when speaking to each other to be influenced by what the other person saw, or thought he saw. One witness may have seen the rotating beacon and thought that it was a fire. If another witness overhears this, he may doubt his own powers of observation and convince himself that he also saw a fire.

3. Do not use leading questions. It is very easy for an interviewer to lead a witness entirely astray by asking questions which may help the witness to fill in the gaps in what he saw.

4. Allow the witness to talk. The interviewer should be willing to listen to the witness and ask as few questions as possible. After all, it is the witness who is being interviewed, not the interviewer.

5. If at all possible, take the witness to the point from where he saw the accident. Sometimes it is useful to use a stopwatch to record relative times. For example, if a witness saw a helicopter in trouble through his window and ran out of the house just in time to see the impact, this may provide a useful clue in measurement of the sequence of events. Remember, that witnesses seldom can make accurate estimations of time when a tragic and shocking event is occurring.

6. Try to determine the credibility of the witness without labelling him. For this purpose, a credibility chart is often useful. A simplified example of a credibility chart follows:

Event / Witness	Fire	Explosion	Parts Fly off	Heading	Heading
Witness A	X	X		X	
Witness B			X		X
Witness C		X	X		X
Witness D		X			X
Witness E		X			X

In this example, it can readily be assumed that Witness A is unreliable and that the helicopter was heading north and that there was an explosion. In addition, it is likely that parts did fly off the helicopter but this could be confirmed by the findings at the accident site and also by noting where the observer was standing.

7. It must be remembered that the attitudes of fellow pilots and acquaintances may be influenced by feelings of loyalty towards the pilot involved in the accident. Not infrequently the author has heard fellow pilots state: "I can't understand what happened. He was one of the best and most cautious pilots in the world." However, weeks or sometimes even months later, reports quite to

the contrary start filtering back. These, too, must be taken with a grain of salt, as they may be an effort on the part of fellow pilots to rationalize the cause for the accident as a self-protective mechanism.

Often many points in the human factors investigation must be obtained from interviewing family members, fellow pilots, employers, etc., and the attitudes of these individuals must always be considered. Very often, they will be reluctant to disclose any information which may implicate either themselves or the pilot in any wrong doings pertaining to a human factors-caused accident. For this reason, a human factors investigator must carefully catalogue any information volunteered to him and try to substantiate this information with fact. For example, during the process of one investigation, the author heard via the grapevine that the pilot had been suffering from fainting spells for several months preceding the accident. However, substantiation was not available, so this factor has to be disregarded in the final analysis.

Accident Site Survey

Aside from photographs, sketches and a rough survey of the accident site are useful and necessary adjuncts to the investigator. If at all possible to attain them, aerial photographs of the overall site can be of great assistance in this regard. However, it is still a good idea if time permits to do a rough survey of the terrain, marking the location of parts, trees and other obstacles, and in particular, marks which are always present at an accident site. Although in some instances, it may be necessary to hire the services of a professional surveyor if great accuracy is demanded, it is often possible to make a very good topographical survey by using a compass and a tape measure to determine the distance and relative bearing from a bench mark or fixed reference point, and by using an inclinometer to determine the relative elevation. Using the data collected in this manner, a fairly accurate topographical map of the accident site can be drawn to scale when time is available.

It is very important that the length and depth of land gouges be measured and recorded for use in mathematical calculations of the crash kinematics. These should be measured for the initial, principal, and secondary impacts, and the distance between the marks should be recorded on the drawing. In order to make calculations pertinent to the determination of crash survivability it is also important to measure the total stopping distance, both vertical and horizontal of the helicopter. This should include the total of the gouge marks, plus the structural collapse of the machine, e.g., in a high rate of descent accident the vertical stopping distance would be the total of the depth of impact marks, plus fuselage and seat deformation, while the horizontal stopping distance would include the length of the skid marks, plus the horizontal structural collapse.

It is essential to devote attention to marks on the ground made by the rotors as these can yield many clues related to the rotor r.p.m. on impact, etc. Tail rotors leave a distinctive mark and flecks of paint may be found in the gouge. In addition, the tail skid or "pogo stick" mark is often found alongside. That the marks are indeed caused by the tail rotor may be confirmed by the appearance of scratches and dirt on the tail rotor tips and the distinctive shear patterns which occur in tail rotor strikes. Also, torsional twisting of the tail rotor drive shaft will be evident if power was being applied when the tail rotor struck the ground.

In calculating the crash kinematics involved in the accident, it is also necessary to measure the terrain angle and, if there are witness marks in trees, etc., the flight path angle. This can be done by using an inclinometer to measure the angle from the horizontal. Similarly, if the distance from the spot where the angle was measured to the object, for example, a tree, is known, the height of the object may be determined. For example, if the top of a tree 100 feet away is determined to be 15 degrees above the horizontal, the height of the tree is equal to 100 X the tangent of 15 or 26.8 feet.

Pathological Examination

A detailed pathological examination in the case of fatal accidents should never be overlooked under any circumstances. Many clues regarding the impact deceleration forces and the sequence of the accident may be derived by careful scrutinization of injury patterns by a qualified, patient pathologist. In the case of nonfatal accidents, again various injury patterns may provide important clues related to the accident. The survivability of helicopter accidents will be discussed in more detail later, but the following statistics may be of interest at this time. Approximately 30% of deaths in survivable accidents are due to burns. Post crash fires occurred in 9% of the light observation helicopter accidents, 33% of the utility accidents and 82% of cargo accidents in a USABAAR survey. Fatal burns were sustained by three out of four fatalities which occurred in cargo helicopter accidents. Fires in many of these cases resulted from displacement of the transmission, resulting in severed oil lines, hydraulic lines, and electrical wires. Incidentally, displacement of the transmission into the passenger compartment occurred in one out of four accidents, resulting in 13% of the fatalities in survivable accidents.

Impact injuries resulted from two broad categories of causes:

1. Contact injuries resulting from forceful contact between the occupant and the cabin structure, or objects within the cabin and compression fractures of the vertebrae. Another example of this is the "chin-sternum-heart" type injury as described by Simpson and as seen by the author on two separate instances.

2. The three most common injuries in survivable accidents are lacerations, fractures, and burns. The most common major injury is open fracture of the tibia resulting from involvement with the console while the feet are rigidly planted on the pedals. Aside from injuries to the back, ranging from strain and bruising to compression fractures, most body injuries result from flailing and tend to be located peripherally:

Upper limb	-	22%
Lower limb	-	20%
Back	-	13%
Head	-	11%
Face	-	10%
Chest	-	8%
Generalized	-	6%
Abdomen	-	4%

Neck	-	4%
Pelvis	-	2%

The causes of death in survivable accidents are summarized as follows:

Burns and complications	-	30%
Multiple extreme trauma	-	18%
Head injuries	-	15%
Hemorrhage and shock	-	9%
Heart/great vessel trauma	-	9%
Hemopneumothorax	-	8%
Chemical pneumonia	-	8%
Drowning	-	3%

In non-survivable accidents, the major cause of death is multiple extreme trauma, often complicated by fire. Head injury is the second most important cause of death. Incidentally, a common source of head injury in survivable accidents is due to the pilots removing their helmets after impact. Victims of habit, they are sprayed with flammable liquids or lacerated by jagged metal, or struck by still revolving parts.

The main purposes for doing an autopsy on an aviation crash victim are summarized as follows:

1. Identification

2. Injury patterns

3. Sequentialization

4. To determine the existence or non-existence of predisposing disease.

5. To determine the G loading on the body which may aid in calculations involving the crash kinematics.

6. Biochemical

   (a) Alcohol profile
   (b) Carbon monoxide
   (c) Lactate profile
   (d) Drugs and other toxicology

It is important that the human factors investigator be present, if at all possible, during the performance of the autopsy. He should carefully catalogue all external injuries and internal trauma. X-rays, particularly of the spine and extremities, should be taken whenever possible. The investigator should aid the pathologist in the collection of tissue specimens and blood for toxicological analysis. These should be suitably labelled, placed in appropriate containers, and immersed in a deep-freezing mixture of saline and ice to prevent further degradation. It is also important that the autopsy be performed at once - it should be construed as being a medical emergency.

Accident Reconstruction

The accident investigator and his colleagues now have in their possession a large amount of data, including the witnesses' statements, wreckage distribution, and breakage patterns, and pathological data which may aid in the reconstruction of the accident sequence. However, the investigation is far from being over, as the onerous task of fitting this information together into a logical sequence lies ahead. An attempt must be made to correlate and explain details of breakage patterns, both in the human and the machine. It is often useful to roughly reassemble parts of the machine without disturbing broken surfaces (as a metallurgical analysis may be required).

Unfortunately, in the case of helicopter accidents, detailed correlation becomes very difficult as, often, no consistent pattern exists. For example, in accidents due to loss of control, the aircraft strikes the ground in a random fashion.

Several trends in helicopter accidents are of interest. Many accidents result from striking obstacles such as trees. In these accidents, the rotor tends to "climb" the tree, causing the machine to fall on its opposite side. Transmission displacement may be evident as shown in photograph 10-2 and this may not only explain an injury, but may also provide valuable evidence in that it will be displaced forward if the retreating blade strikes first, and rearward if the advancing blade strikes first. In certain helicopters, cockpit penetration by the rotor or stabilizer bar is very common.

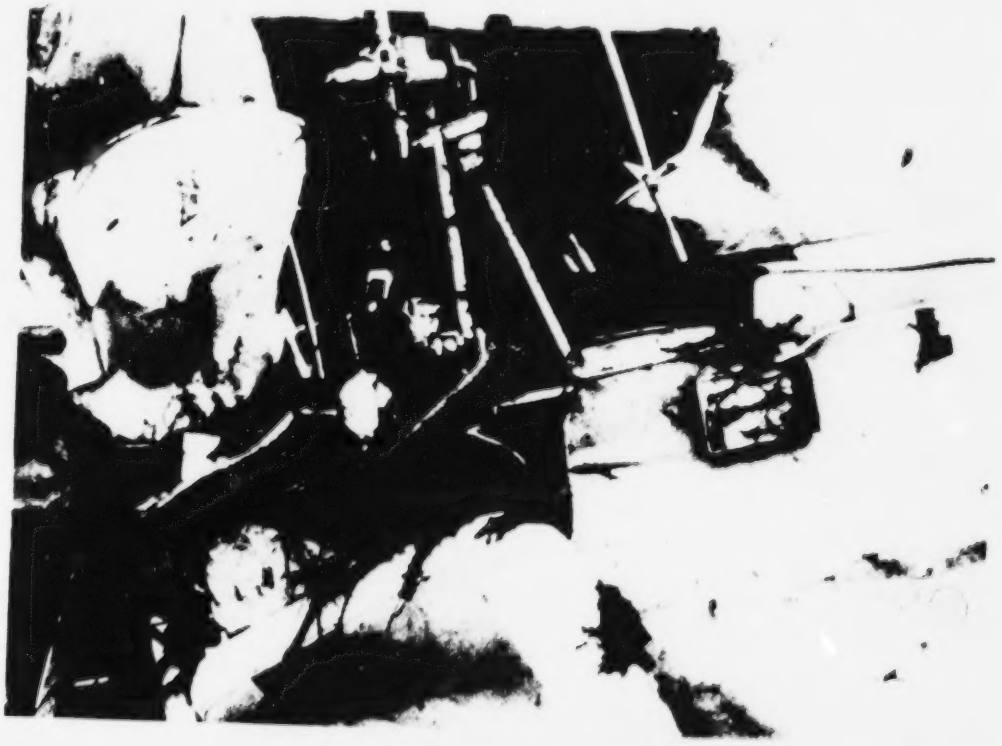


Photo 10-2

As helicopter accidents often involve a high sink rate, it is not uncommon for the main rotor to slice through the tail rotor drive shaft or the tail boom, e.g., photograph 10-3 shows the result of an autorotation with an ensuing hard touchdown.

Often it is possible to determine the cause of main rotor damage by careful correlation of paint marks, etc. Photograph 10-4 shows the roughly assembled horizontal stabilizer.

Photo 10-3

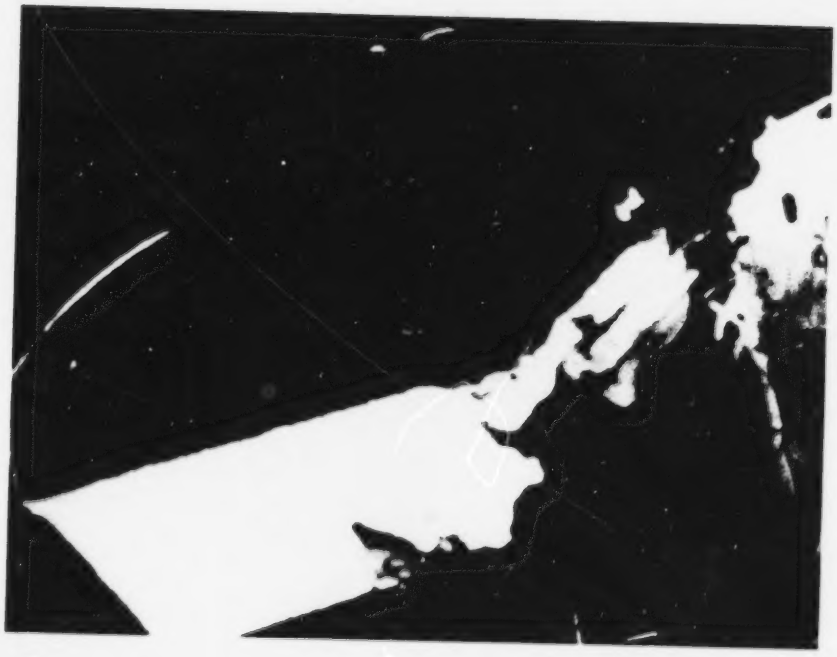


Photo 10-4

It can be seen that the main rotor cut through the horizontal stabilizer of the helicopter. A small section of the aluminum spar of the horizontal stabilizer was found embedded in the main rotor as shown in photograph 10-5.

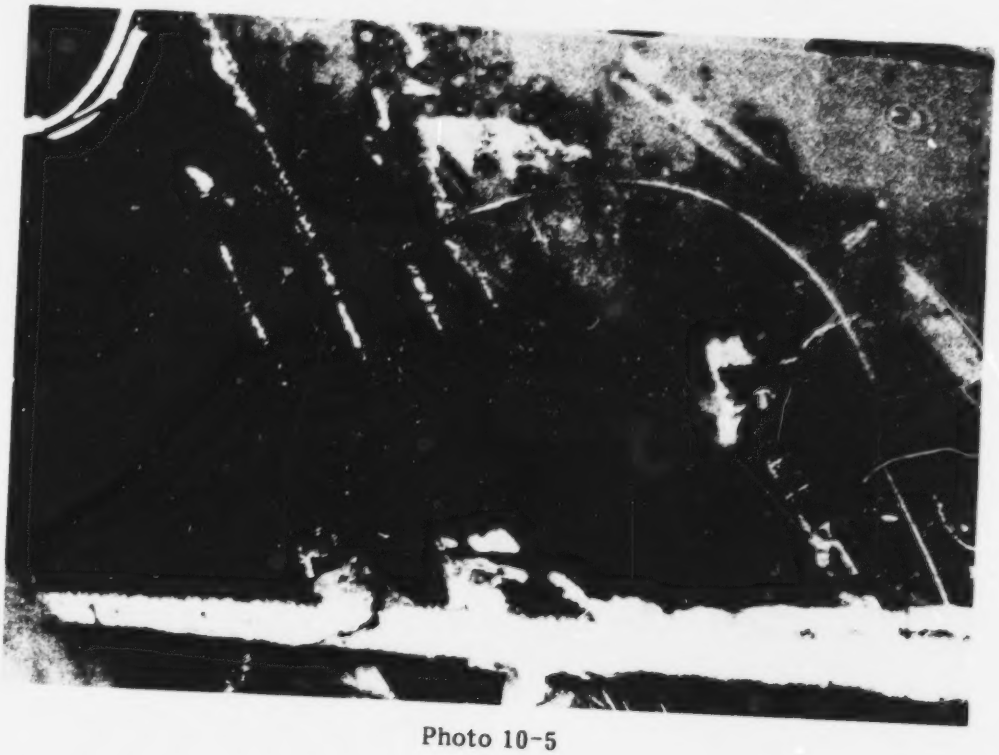


Photo 10-5

Photograph 10-6 shows a circular punched-out area in the main rotor. This was correlated by fitting the end of the cross tube into the opening and it was decided that this occurred during rollover.

Photo 10-6

Finally, if there is a suspicion of material failure, these parts should be carefully preserved for future analysis at an experienced laboratory. This may include an engine teardown, and for this reason no attempt should be made to rotate the crankshaft, etc.

Accident Examples

CASE 1 At approximately 1500 hours on a summer's afternoon a helicopter, while engaged in a commercial operation, attempted to do a standard transition out of a confined area. As the helicopter picked up speed and approached the trees, the pilot attempted to gain altitude by increasing collective pitch, but saw he was unable to clear the trees and that his rotor r.p.m. had decayed, so he initiated a left-pedal turn and attempted to land under power.

The final result is shown in photo 10-7. The pilot sustained no injuries, (except perhaps to his pride).

Photo 10-7

Normally, to takeoff from a confined area, the pilot will sacrifice air speed for altitude, i.e., he will first gain altitude and then begin his transition. To attempt a standard running transition out of the confined area is foolish at the best of times. An additional factor in this case was a 15 mile-an-hour head wind which would create some subsidence at the edge of the clearing just where he would be attempting to gain altitude. By applying left pedal, the rotor r.p.m. further decreased because of the additional power required in a left-pedal turn.

It appears that the cause of this accident was an error in judgment. In reviewing the pilot's flying history, it was discovered that during the days immediately preceding the accident, he had been flying 9 to 11 hours per day. It was his habit to arise early in the morning, have a hearty breakfast, and then fly all day without stopping for further sustenance until approximately 8 P.M. At the time of the accident, his blood sugar would be at a low ebb and this along with flying fatigue could have contributed to the error in judgment.

CASE 2 In Canada's high Arctic, a helicopter disappeared during a test flight with three occupants on board. The helicopter was found the next day. The crash was characterized by a fairly level impact with a major downward component of deceleration. The aircraft had rolled over onto its back, throwing the two passengers outside. (See photo 10-8) The pilot's body was found inside the aircraft. All three occupants died from trauma, the pilot suffering from a severe head injury. The condition of the bodies indicated a major vertical component of deceleration in the magnitude of greater than a 25 peak G deceleration.

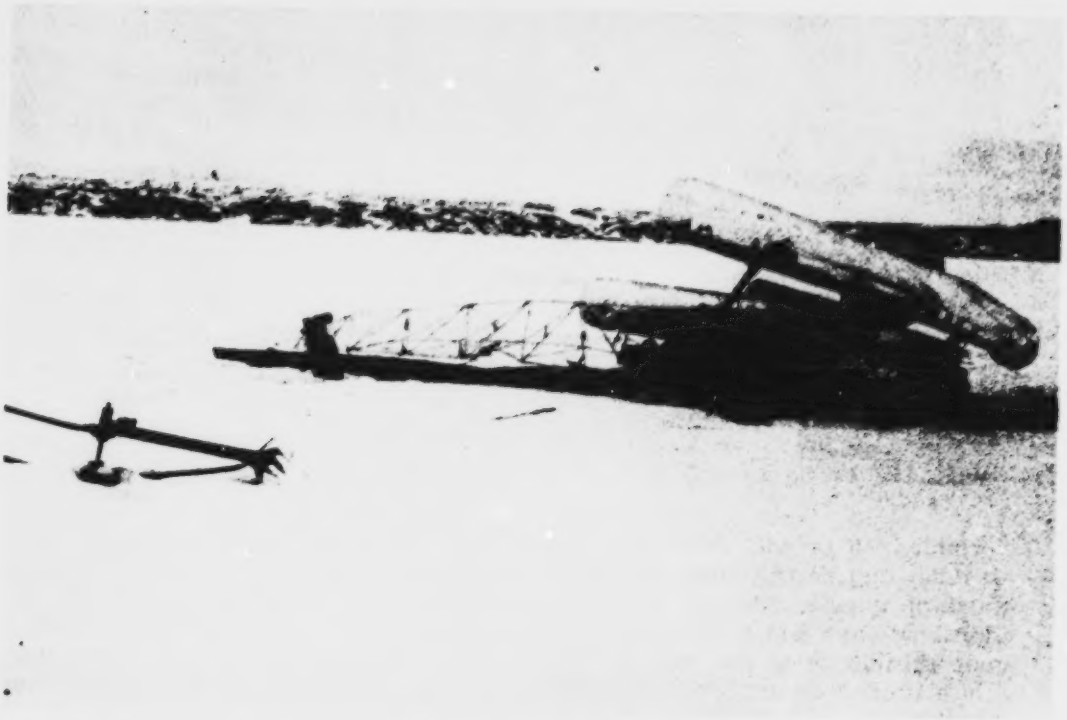


Photo 10-8

The pilot had been a helicopter pilot in the Armed Forces and had a total time of more than 1000 hours on helicopters. In the 90 days previous to the accident, he had flown seven hours, and in the previous 48 hours had flown one trip of approximately 15 minutes. The helicopter was ferried to the north, the pilot and the engineer accompanying it in a DC-3. Apparently, the two had begun consuming alcoholic beverages as soon as they left home and remained inebriated for the entire trip. Upon arrival in the north, the pilot and engineer began assembling the helicopter and, according to witnesses, they were both consuming alcohol while on the job. Upon completion, the pilot did a 15-minute test flight and because he was not satisfied, the engineer made further modifications.

On the day of the accident, the pilot and engineer, along with an acquaintance, began drinking early in the morning and continued drinking all day. Towards evening, the trio indicated that they were going to go for a flight, although a number of employees at the camp tried to dissuade them. As they proceeded to the aircraft, they were observed to be carrying alcoholic beverages.

The pilot's post-mortem blood alcohol was found to be .12, which is far beyond the legal limit for operating a motor vehicle. It is well known that a level of .02 can result in impaired flying, and recent studies which attempted to measure the performance of individuals under the influence of different concentrations of alcohol found no level of alcohol that did not result in serious impairment.

This helicopter accident was not survivable, based on the amount of cockpit distortion and peak of G loading. The aircraft did not burn as there was no fuel remaining in the tanks.

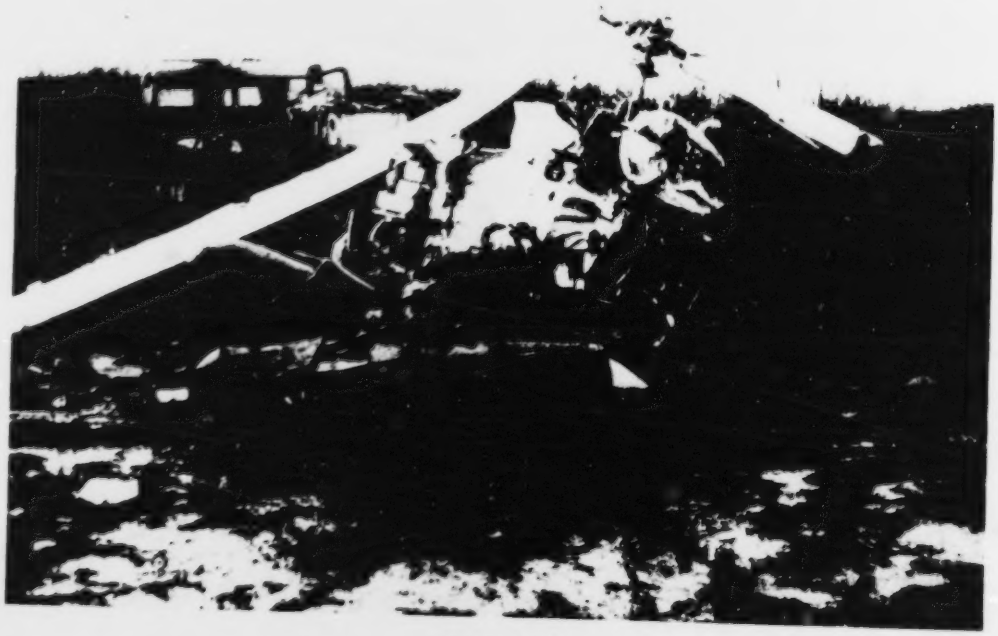


Photo 10-9

CASE 3 At approximately 1500 hours, a helicopter with two persons on board, disappeared while performing a powerline patrol in bush country. The helicopter was later found in close proximity to the powerline (see photo 10-9). Both occupants were killed in the crash. The wreckage of the helicopter was widely scattered and the main wreckage was distorted, as it had likely cart-wheeled in the muskeg. The left float was attached partly to the skids of the helicopter, but the right float was located beyond the helicopter, in the direction of the flight path. Parts of the helicopter such as plexiglass, parts of the tail boom, and the battery, were located several hundred feet away from the main body of the wreckage. The horizontal stabilizer had been cut diagonally in half by the main rotor and control cable marks were found on one of the rotors (see photo 10-5). Following rough reassembly of the metal supports for the left float, which had been found at least 100 feet away from the body of the float, a cable mark was discovered (see photo 10-10).

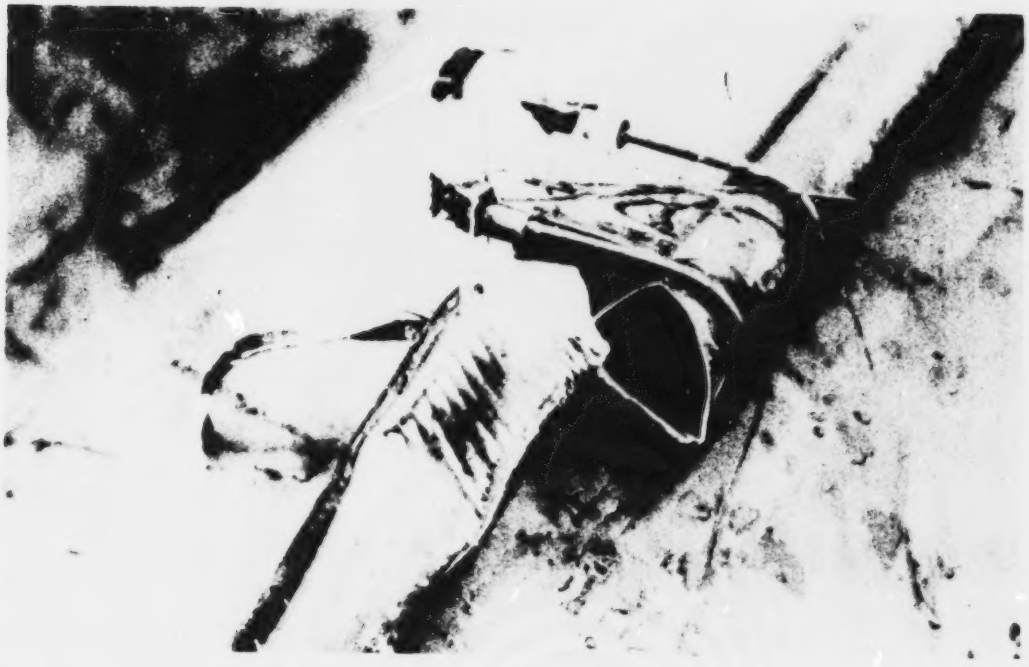


Photo 10-10

The hydro lines were then inspected and it was thought that one of the vibration dampers on the sky-line had been stretched somewhat. The author then surveyed the scene from the air in a helicopter (see photo 10-11).

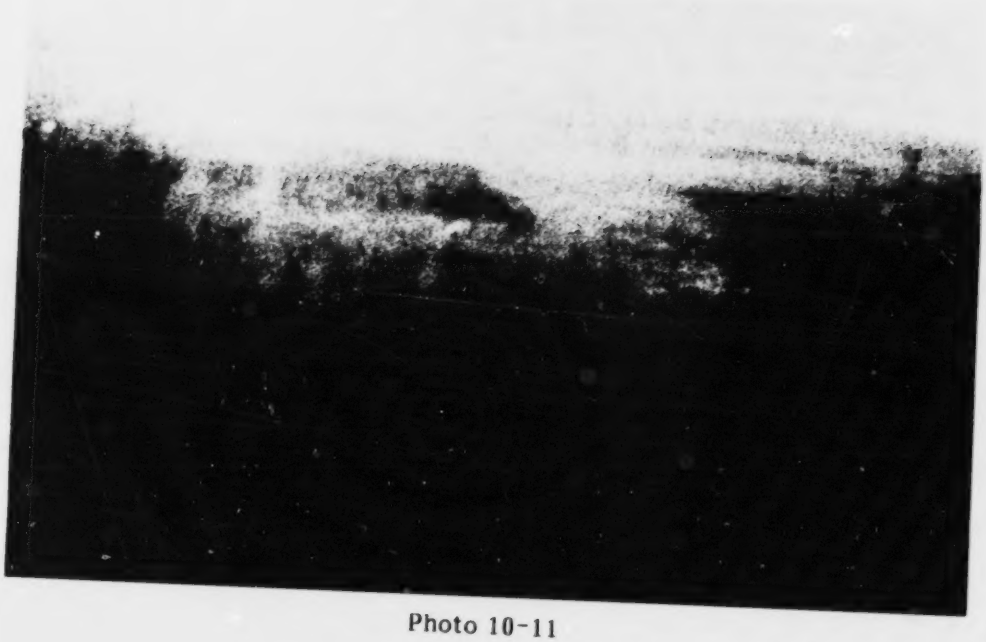


Photo 10-11

Several things became obvious: The pilot of the crashed helicopter had been patrolling a line which was to the right and lower than the line over which he had been flying. The two adjacent lines divided and swung to the left, giving one the impression that there was a large area available in which to turn. However, an additional and even higher line crossed perpendicularly to the flight path. From the pilot's position immediately prior to the accident, the poles on this line appeared to belong to the line he was patrolling. In addition, in the background, was a tree line, a lake with a fairly straight shoreline, and a factory. Smoke from the factory was drifting across the field of vision in the distance, thus providing poor visual contrast for the higher powerline. Because this was a recent crossover, there was no warning marker, which is normally found two structures prior to crossover. All other crossovers were marked and therefore the pilot would not be expecting to see a crossover line. His perception of this line would be reduced by the confusing array of tree lines and the shoreline in the distance, as well as the smoke which reduced the contrast between the powerline and the horizon.

It was, therefore, concluded that the helicopter struck the skyline with the left float and flipped over, severing the tail boom in mid-air and impacting in the muskeg.

CASE 4 While on a night flight in poor weather with scattered snow-shower, a helicopter disappeared over a lake. No sign of the helicopter was found until the next spring, when the floats and various other parts of the machine were found on the shore of the lake, some of the parts being as much as 27 miles apart. The pilot's body was recovered in entirety in the late spring, and a decomposed right leg was discovered by some fishermen

in the autumn of the same year. The leg was positively identified as belonging to the left front seat passenger by means of a surgical plate which was attached to the mid-shaft of the tibia. Careful analysis of the fracture patterns was made. As can be seen in the X-rays (photo 10-12, 10-13) the small bones of the foot had been fractured at approximately a 45-degree angle, and the shaft of the tibia was fractured with the lower aspect displaced posteriorly.

In addition, the femur was fractured and the ischial tuberosity was fractured and partially avulsed. It was believed that the femoral and ischial fractures likely resulted from a shallow high-speed impact with the water (which corresponded to the damage patterns in the parts of the wreckage found). It was also felt that the only way in which the metatarsal bones could be fractured in such a manner was if the occupant had his feet flat on the floor and his foot struck the foot-rest during the deceleration. Normally, when a person is acutely startled and anticipates a collision, he thrusts his right leg outward as if to apply brakes, which, in this case, would have resulted in a different fracture pattern. It was, therefore, assumed that the passenger, at least, did not anticipate the impact. The accident probably resulted from disorientation and conditions of extremely poor visibility.

This accident illustrates the wealth of data which can be obtained from a minimum of evidence if careful scrutiny and analysis is performed. The investigator must be extremely inquisitive and observant, and should attempt to explain every little anomaly that he sees, and must be able to utilize positive as well as negative evidence in performing the final analysis in helicopter accidents.

For further details concerning human factors investigation, see the two checklists, Appendices A and B.

Photo 10-12

Photo 10-13

CHAPTER XI

CRASH KINEMATICS

"The application of a few simple formulae may unlock secrets which would otherwise remain forever concealed in the confusing rubble of an accident."

Photo 11-1

One of the very important aspects of the Human Factors Investigation in any type of aircraft accident is an evaluation of survivability. The objectives of a crash survival investigation are threefold:

1. To determine the cause of injuries which occur as a result of an accident.

2. To isolate the factors which help prevent or reduce injuries.

3. To use the knowledge gained from individual accident investigations to provide maximum occupant protection throughout a crash.

For an accident to be survivable two conditions must exist for at least one occupant.

1. The impact forces on the occupant must not exceed the limits of human tolerability to abrupt deceleration, and

2. The fuselage structural container must maintain a livable volume around the occupant.

Though an assessment of the second conditions i.e., cockpit deformation can be made easily in the field, it is obvious that in order to determine the peak "G" loading on the occupants, a basic knowledge of mathematics is necessary in order that calculations can be made. Although these calculations may occasionally be very complicated and difficult and require the assistance of a qualified engineer or physicist, often the Human Factors Investigator can make simple assessments regarding survivability by using a few basic formulae and equations.

Trigonometry

Most readers of this publication will have had a background in trigonometry at some time in their lives. However, human memory being what it is, it is probably appropriate to review some of the basic concepts of mathematics as applied to triangles. This discussion will be restricted to right angle triangles as most problems may be solved using this type of triangle.

First of all, the right angle triangle is a three-sided, geometric figure, possessing one angle of 90. It is true of all triangles, that the total of the angles is 180.Figure 1 shows a right angle triangle, with angle C being 90. Obviously, the total of angles a, b and c is 180.In the terminology of right angle triangles , side AB is called the hypotenuse and is the longest side of the triangle.

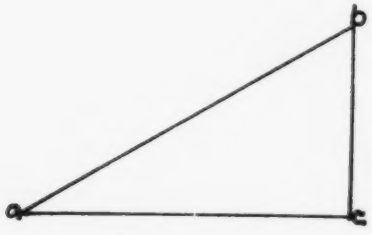


Fig. 11-1

Trigonometric Functions

One of the truly remarkable aspects of right angle triangles is that for any given angle, the ratio of any given sides is constant. For example, if angle "a" is 30, the ratio of the sides BC and AB will always be 0.5 i.e., AB will be twice as long as BC no matter how long AB is. Far back in human history this fact was recognized by some clever mathematicians and they set about tabulating the ratios of sides according to angles. These ratios are known as trigonometric functions, and for the purposes of

calculating crash kinematics this discussion can be limited to the use of sines, cosines, and tangents abbreviated sin, cos, and tan. Clarification of these definitions may be provided by the following table:

Table 1

Sine (sin)	=	$\frac{\text{Opposite}}{\text{Hypotenuse}}$, e.g. sin a =	$\frac{BC}{AB}$
Cosine (cos)	=	$\frac{\text{Adjacent}}{\text{Hypotenuse}}$, e.g. cos a =	$\frac{AC}{AB}$
Tangent (tan)	=	$\frac{\text{Opposite}}{\text{Adjacent}}$, e.g. tan a =	$\frac{BC}{AC}$

Note that the examples in this table include the trigonometric functions for angle "a". The side opposite to angle "a" is BC while the side adjacent to angle "a" is AC. Obviously, the hypotenuse is AB.

The investigator, now armed with this information, can find the unknown angles "a" or "b" by knowing the length of at least two of the sides, or can find the unknown length of a side by knowing either the length of two of the sides or by knowing one of the angles and one of the sides.

Example Problems - for the convenience of the reader, a simplified trigonometric table is provided as Appendix B of this publication.

Problem 1 - The investigator is 150 feet away from the base of tree. Using his inclinometer he determines that the relative elevation of the top of the tree is 15. Determine the height of the tree. Solution: let the height of the tree equal X.

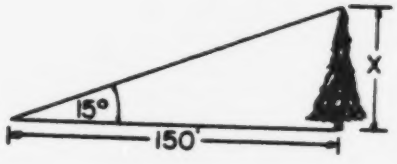


Fig. 11-2

$$\tan 15 = \frac{X}{150}$$

therefore X = 150 tan 15 = 40.2 feet

Problem 2 - An accident investigator is required to find the width of a river. However, the river is too wide to measure with a tape, but a bridge runs across the river at a 20 angle from the shore and the investigator finds that the length of the bridge from shore to shore is 150. Find the width of the river. Solution: let the width of the river equal Side X on a right angle triangle as shown on the diagram.

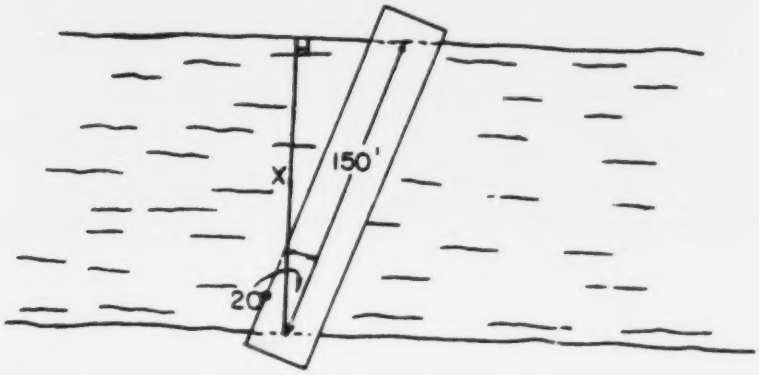


Fig. 11-3

The cosine of 20 would equal:

$$\cos 20 = \frac{X}{150}$$

therefore X = 150 cos 20 = .940 x 150 = 141 feet

therefore the river is 141 feet wide.

Armed with this basic knowledge of fundamental trigonometry, an accident investigator can perform many useful calculations. The importance of measuring angles and distances now becomes obvious. To thoroughly understand the applications of trigonometry in aircraft accident investigation, the following definitions become necessary.

1. Terrain Angle - The angle between the impact surface and the horizontal, measured parallel to the vertical plane of the flight path, in the direction of flight. The algebraic sign of the terrain angle is positive when the direction of flight is uphill, and negative when the direction of flight is downhill.

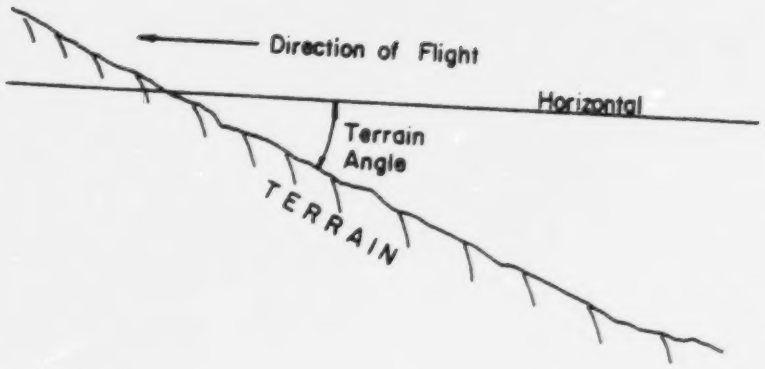


Fig. 11-4 -

Fig. 11-5

2. Flight Path Angle - The angle between the aircraft flight path and the horizontal at the moment of impact is the flight path angle. The algebraic sign of the flight path angle is positive if the aircraft is moving downward immediately prior to impact. The sign is negative if impact occurs while the aircraft is moving upward. In the latter case, some imagination is required to visualize an aircraft moving upward at the time of impact. However, if one remembers that helicopters are often involved in mountain flying, the implication is obvious.

3. Impact Angle

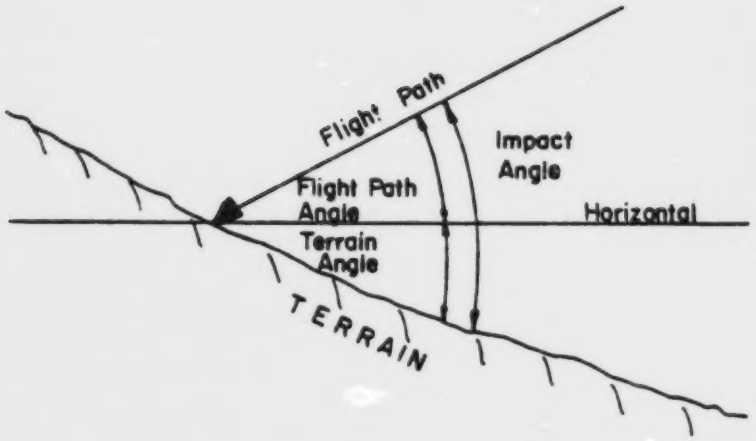


Fig. 11-6

The angle between the flight path and the terrain, measured parallel to the vertical plane of the flight path represents the impact angle. The impact angle is the algebraic sum of the flight path angle plus the terrain angle.

IMPACT ANGLE = FLIGHT PATH ANGLE + TERRAIN ANGLE

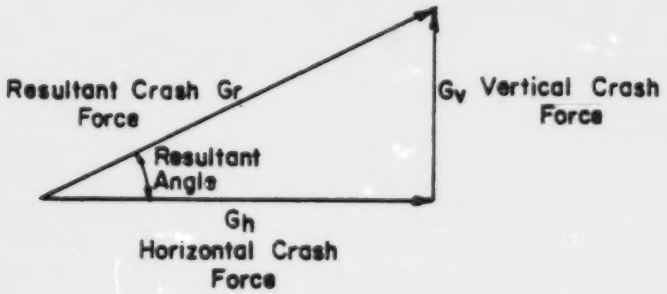


Fig. 11-7

4. Crash Force Resultant - This is the geometric sum of horizontal and vertical crash forces (horizontal and vertical crash forces are determined on the basis of horizontal and verticalvelocity components at impact, and horizontal and vertical stopping distances).

The crash force resultant is fully defined by determination of both its magnitude and its direction. The algebraic sign of the crash force resultant angle is positive when the line of action of the resultant is above the horizontal, and negative if the line of action is below the horizontal.

5. Attitude of Impact - This is the attitude of the aircraft at the moment of initial impact. The factors to be considered in determining the attitude at impact are:

(a) Pitch - nose above horizon or below horizon

(b) Yaw - nose right or nose left

(c) Roll - right or left bank

The attitude at impact is to be determined as accurately as possible in degrees. The algebraic sum of the aircraft pitch angle is negataive when the nose of the aircraft points below the horizon, and positive when the nose points above the horizon.

6. Crash Force Angle

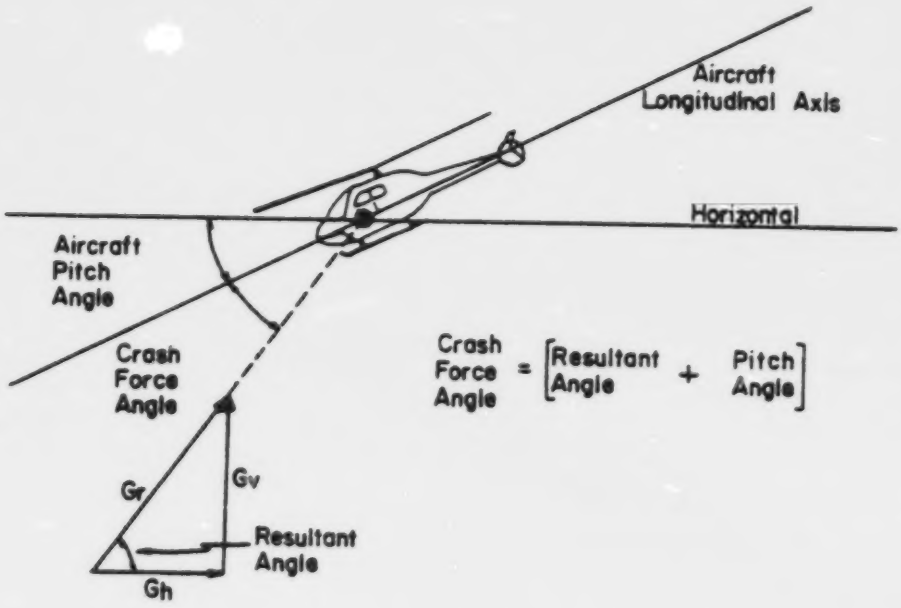


Fig. 11-8

The angle between the resultant crash force and the longitudinal axis of the aircraft is the crash force angle.

For impacts with little lateral component of force, the crash force angle is the algebraic sum of the crash force resultant angle plus the aircraft pitch angle.

Acceleration

In performing an investigation of a helicopter accident or, for that matter, an accident involving any type of vehicle, be it aircraft or automobile, it is important to understand the use of mathematical relationships related to acceleration. These concepts become particularly useful during the investigation of the survivability of an accident as part of the definition of survivability involves acceleration.

Acceleration may be defined as the rate of change of velocity. Whenever a change in velocity occurs, acceleration also occurs. Accelerations may produce an increase or decrease in velocity and accelerations which produce a decrease in velocity are sometimes called decelerations. Although there are two basic types of acceleration, i.e., "linear acceleration", which produces a simple change of speed while the direction of motion is unchanged, and "rotational acceleration", which produces a change in speed of rotation and may also produce change in rotational direction, the latter will be disregarded in this section. Acceleration (rate of change of velocity) may be constant as times passes (constant acceleration) or acceleration may vary as time passes (variable acceleration). Mathematically acceleration may be represented as

$$a = \frac{\Delta v}{\Delta t}$$

where v equals change in velocity and t equals time period during which velocity change occurs.

Linear Acceleration Terms and Symbols:

V_o = initial velocity, the velocity at the beginning of a particular impact pulse. The subscript "o" refers to time o at the beginning of the pulse.

V_f = final velocity, the velocity at the end of a particular pulse. Often a crash involves several definite acceleration pulses and only the last pulse will have a final velocity of o.

S = distance, the standard dimensional unit for distance is feet (ft)

t = time - the standard dimensional unit for time is the second (sec)

V = velocity-usually measured in feet per second

a = acceleration. The rate of change of velocity in feet per second $\frac{ft}{sec^2}$

g = acceleration of gravity. The magnitude of acceleration due to gravity is approximately 32.2 $\frac{ft}{sec^2}$

G = ratio of any acceleration, "a" to the acceleration of gravity, "g" $G = \frac{a}{g}$

G is also used to indicate the magnitude of a force.

$F = M a = M G g$

$M = \frac{w}{g}$ therefore $Mg = W$, therefore $F = WG$ (where W = weight)

In almost the same sense, the term G may also be used in reference to strength. When used in this manner, G refers to the force a structural member or restraint device can withstand.

Equations for Motion with Constant Acceleration

1. $V_f = V_o + at$ If motion begins at rest ($V_o = O$) or ends at rest ($V_f = O$) then the equation becomes: $V_f = at$ or $V_o = at$ respectively.

2. $S = V_o t + 1/2\ at^2$ Again, if motion begins or ends at rest, the equation will become $S = 1/2\ at^2$

3. $V_f^2 = V_o^2 + 2\ aS$ In calculation of impact acceleration, these relationships are useful. The known quantities are:

   s - which is the stopping distance measured during the accident investigation.

   V_f - which is the final velocity after the aircraft has travelled the distance "s" and V_o - initial velocity of the aircraft.

If the unknown quantity is the acceleration "a". Algebraically then,

$$a = \frac{V_f^2 - V_o^2}{25}$$

If the acceleration in G is desired:

$$G = \frac{a}{g} = \frac{a}{32.2}$$

$$G = \frac{V_f^2 - V_o^2}{2 \times 32.2 \times s}$$

Therefore, $G = \dfrac{V_f^2 - V_o^2}{64.4s}$

or, to simplify computations:

$$G = \frac{V_f^2 - V_o^2}{64s}$$

The duration of the acceleration acting upon a body is frequently a matter of interest. This duration in seconds may be determined using any one of the following equations:

$$t = \frac{V_o - V_f}{a}$$

$$t^2 = \frac{2s}{a} \text{ or } t = \sqrt{\frac{2s}{a}}$$

$$t^2 = \frac{2s}{32G} \text{ or } t = \sqrt{\frac{2s}{32G}}$$

Method of Solution of Crash Force Problems

1. Sketch known quantities.
2. Convert known quantities to standard dimensional units.

   Distances = feet

   Velocities = ft/sec
3. Determine magnitude of velocity component.
   (a) parallel to impact surface
   (b) perpendicular to impact surface
4. Determine stopping distance.
   (a) parallel to impact surface
   (b) perpendicular to impact surface
5. Determine acceleration components.

(a) parallel to impact surface

(b) perpendicular to impact surface

6. Determine resultant acceleration magnitude and direction with respect to impact surface.

7. Determine direction of resultant acceleration with respect to aircraft axes.

Example: Problem 1 - A helicopter crashes in a level, open field. The flight path angle is 10 and the true air speed is 85 m.p.h. The initial impact occurs with the fuselage level (0 pitch angle). The impact causes a 2-foot deep gouge and comes to rest 25 feet from initial impact. The fuselage is crushed 12 inches vertically and 5 feet horizontally. Find:

1. Aircraft ground speed (V_h) and vertical velocity (V_v) in feet per second.

2. The mean vertical and horizontal accelerations in G.

3. The magnitude and direction of the mean crash resultant.

Solution:

1. To find V_h and V_v

(a) sketch conditions at impact

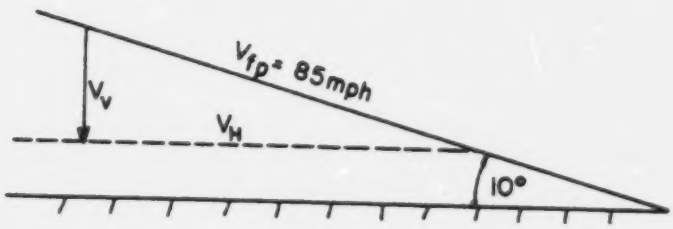


Fig. 11-9

(b) convert 85 m.p.h. to feet per sec. 85 m.p.h. = 125 ft per sec.

(c) determine vertical and horizontal velocities

1. $\sin 10° = \frac{V_v}{V_{fp}}$

$V_v = V_{fp} \times \sin 10°$

$V_v \times 125 \times 0.174 = 21.7$ ft. per sec.

2. $\cos 10° = \dfrac{V_h}{V_{fp}}$

$V_h = V_{fp} \times \cos 10°$

$V_h \times 125 \times 0.985 = 125$ ft. per sec.

2. To find G_v and G_h

(a) determine vertical and horizontal stopping distances

1. Vertical stopping distance

= 2 ft (gouge) + 1 ft. (structure) = 3 ft.

(b) determine vertical and horizontal accelerations (G)

1. Since the aircraft ends at rest, the simplified equation is used

$$G = \frac{V^2}{64s}$$

$$G_v = \frac{(21.7)^2}{64 \times 3} = 2.45 \text{ G}$$

$$G_h = \frac{(123)^2}{64 \times 30} = 7.87 \text{ G}$$

3. To find the resultant acceleration:

(a) sketch the vector diagram of the impact accelerations

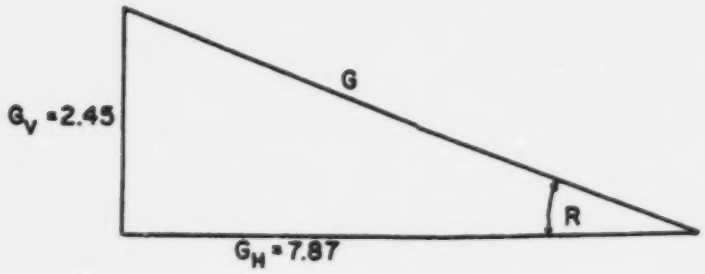


Fig. 11-10

The direction of the resultant acceleration may be found using the tangent trigonometric function -

$$\tan R = \frac{G_v}{G_h} = \frac{2.45}{7.87} = 0.311$$

Therefore: Angle R = 17.3°

The magnitude of the resultant acceleration may be found using the cosine function

$$17.3° \qquad \frac{7.87}{G_R}$$

$$G_R = \frac{7.87}{\cos 17.3°} = 8.25\ G$$

Deceleration Pulses

The equations and problem solving as shown in the previous section relates to constant decelerations. In actual aircraft crash kinematics it is very seldom that deceleration levels are constant. Therefore, it becomes necessary to understand the relationships of displacement, velocity and acceleration with time in various pulse shapes. Figure 11-11 shows an acceleration time curve of a common type encountered in actual impact situations.

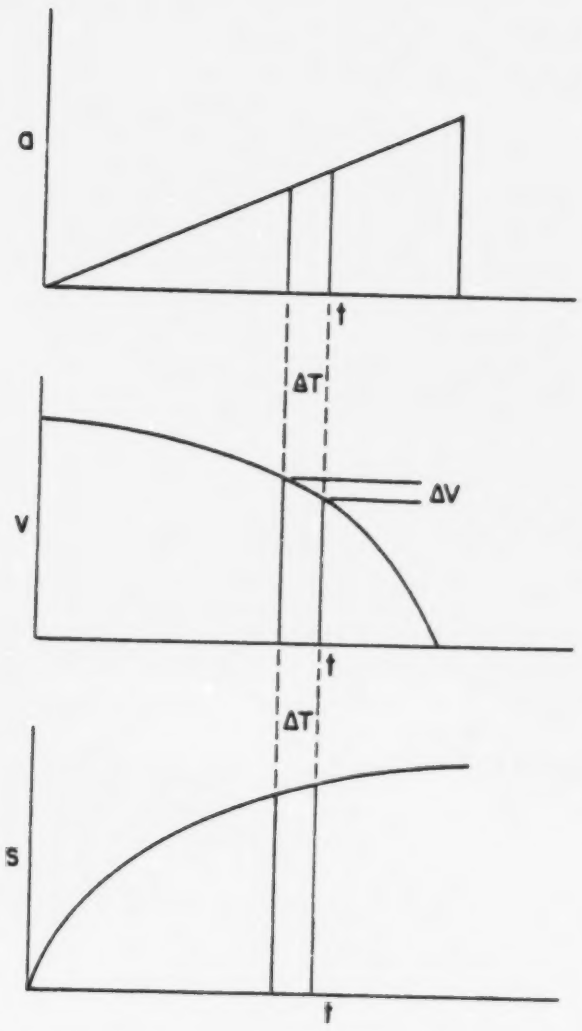


Fig. 11-11

Immediately beneath the acceleration time curve "a" is the velocity time curve "v", Figure 11-11. During any period of time (Δt) taken along the acceleration time curve, the height of the "at" curve is equal to the slope of the "vt" curve, the slope of the "vt" curve equalling $\frac{\Delta v}{\Delta t}$

Therefore, the maximum slope of this curve occurs where acceleration is at its highest peak, which is at the final part of the pulse.

It should also have been noted that the area under the acceleration time curve during the period Δt is equal to A X Δt = Δv.

The bottom curve discloses the relationship between distance (s) and time (t). The slope of the "st" curve must be equal to the height of the "vt" curve and, therefore, whereas the "vt" curve is a secondary curve, the "st" curve then becomes a tertiary curve.

Since the height of the "at" curve is numerically equal to the slope of the "vt" curve, $a = \frac{\Delta v}{\Delta t}$ and since the height of the "vt" curve is equal to the slope of the "st" curve, $v = \frac{\Delta s}{\Delta t}$

Since $a = \frac{\Delta v}{\Delta t}$ therefore $v - \Delta t$. If all of the changes in time (Δt) are summed, the total change in velocity becomes the area under the "at" curve. The same condition exists between the "vt" and "st" curves, that is, the total change in position equals the area under the "vt" curve. Therefore,

$$v_o = 1/2 \text{ at } t = \frac{2v_o}{a} \qquad s = 2/3\ v_o t = 2/3\ v_o \text{ X } 2v_o$$

$$= \frac{4/3\ v_o^2}{a} = \frac{4v_o^2}{3a}$$

Therefore, the equations for pulse duration, deceleration level, and stopping distance for this type of triangular pulse, assuming that $v_f = 0$ becomes

Pulse Duration: $t = \frac{2v_o}{32.2G}$

Deceleration Level: $G = \frac{4v_o^2}{96.6s}$

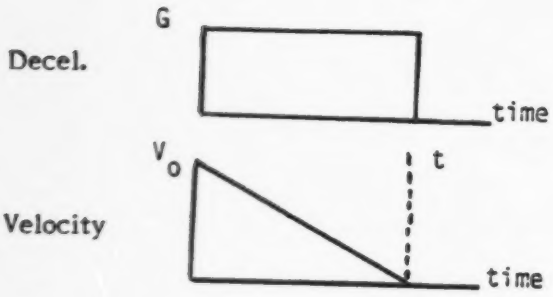
Stopping Distance: $S = \frac{4v_o^2}{96.6G}$ or $S = \frac{32.2Gt^2}{3}$

The deceleration equations for various pulse shapes are summarized in the cases where $v_f = 0$ and where v_f is not equal to zero ($V_f = 0$) on the following pages: It is not intended that these formulae be memorized. The author makes a practice of carrying a copy of these equations in his briefcase. Solving a problem becomes a simple matter of gathering the data and "plugging" in the numbers.

DECELERATION EQUATIONS

FOR THE CASE $V_{final} = 0$

1. RECTANGULAR PULSE



Pulse Duration: $t = \frac{V_o}{32.2G}$

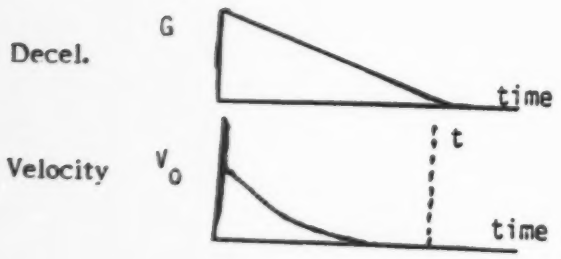
Deceleration Level: $G = \frac{V_o^2}{64.4S}$

Stopping Distance: $S = \frac{V_o^2}{64.4G}$

Or: $S = \frac{32.2Gt^2}{2}$

---

11. TRIANGULAR PULSE NO. 1



Pulse Duration: $t = \frac{2V_o}{32.2G}$

Deceleration Level: $G = \frac{2V_o^2}{96.6S}$

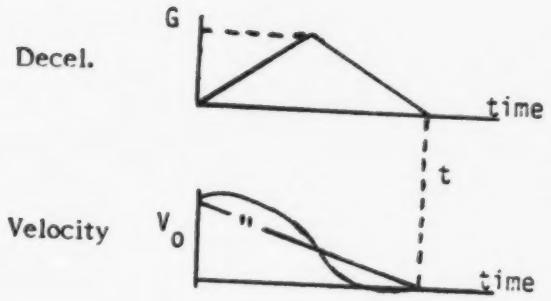
Stopping Distance: $S = \frac{2V_o^2}{96.6G}$

Or: $S = \frac{32.2Gt^2}{6}$

DECELERATION EQUATIONS

FOR THE CASE $V_f = 0$

III. TRIANGULAR PULSE NO. 2



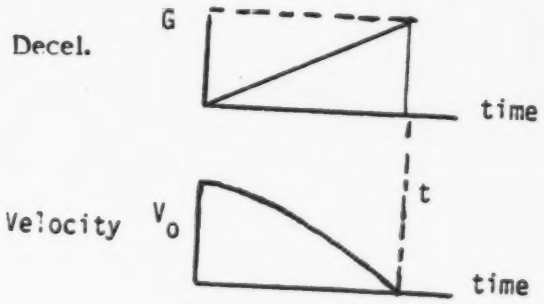
Pulse Duration: $t = \frac{2V_o}{32.2G}$

Deceleration Level: $G = \frac{V_o^2}{32.2S}$

Stopping Distance: $S = \frac{V_o^2}{32.2G}$

Or: $S = \frac{32.2Gt^2}{4}$

IV. TRIANGULAR PULSE NO. 3



Pulse Duration: $t = \frac{2V_o}{32.2G}$

Deceleration Level: $G = \frac{4V_o^2}{96.6S}$

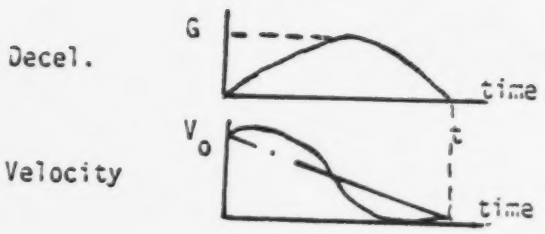
Stopping Distance: $S = \frac{4V_o^2}{96.6G}$

Or: $S = \frac{32.2Gt^2}{3}$

DECELERATION EQUATIONS

FOR THE CASE $V_f = 0$

V. HALF SINE PULSE



Pulse Duration: $t = \frac{1.57V_o}{32.2G}$

Deceleration Level: $G = \frac{0.7854V_o^2}{32.2S}$

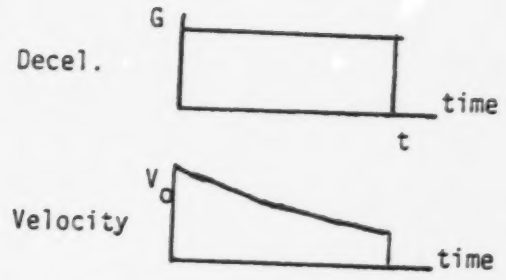
Stopping Distance: $S = \frac{0.7854V_o^2}{32.2G}$

Or: $S = \frac{32.2Gt^2}{3.14}$

DECELERATION EQUATIONS

FOR THE CASE $V_f \neq 0$

1. RECTANGULAR PULSE



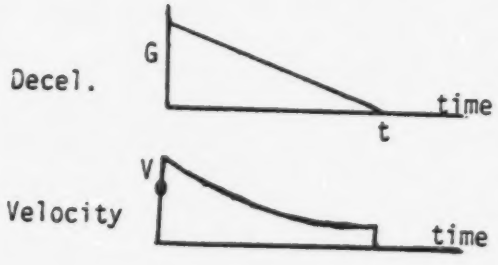
Pulse Duration: $$t = \frac{V_o - V_f}{32.2G}$$

Deceleration Level: $$G = \frac{V_o^2 - V_f^2}{64.4S}$$

Stopping Distance: $$S = \frac{V_o^2 - V_f^2}{64.4G}$$

Or: $$S = V_o t - \frac{32.2Gt^2}{2}$$

II. TRIANGULAR PULSE NO. 1



Pulse Duration: $$t = \frac{2(V_o - V_f)}{32.2G}$$

Deceleration Level: $$G = \frac{2V_o^2 + 2V_oV_f - 4V_f^2}{96.6S}$$

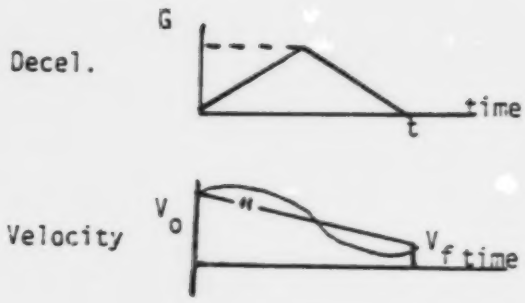
Stopping Distance: $$S = \frac{2V_o^2 + 2V_oV_f - 4V_f^2}{96.6G}$$

Or: $$S = V_o t - \frac{32.2Gt^2}{3}$$

DECELERATION EQUATIONS

FOR THE CASE $V_f \neq 0$

III. TRIANGULAR PULSE NO. 2



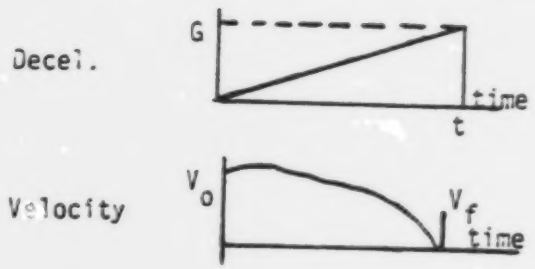
Pulse Duration: $t = \frac{2(V_o - V_f)}{32.2G}$

Deceleration Level: $G = \frac{V_o^2 - V_f^2}{32.2S}$

Stopping Distance: $S = \frac{V_o^2 - V_f^2}{32.2G}$

Or: $S = V_o t - \frac{32.2Gt^2}{4}$

IV. TRIANGULAR PULSE NO. 3



Pulse Duration: $t = \frac{2(V_o - V_f)}{32.2G}$

Deceleration Level: $G = \frac{4V_o^2 - 2V_oV_f - 2V_f^2}{96.6S}$

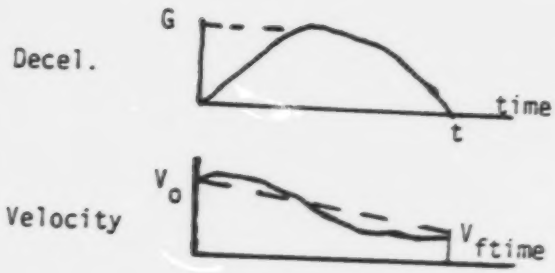
Stopping Distance: $S = \frac{4V_o^2 - 2V_oV_f - 2V_f^2}{96.6G}$

Or: $S = V_o t - \frac{32.2Gt^2}{6}$

DECELERATION EQUATIONS

FOR THE CASE $V_f \neq 0$

V. HALF SINE PULSE



Pulse Duration: $$t = \frac{1.57\ (V_o - V_f)}{32.2G}$$

Deceleration Level: $$G = \frac{0.7854\ (V_o^2 - V_f^2)}{32.2S}$$

Distance: $$S = \frac{0.7854\ (V_o^2 - V_f^2)}{32.2G}$$

Or: $$S = V_o t - \frac{32.2Gt^2}{3.14}$$

Coefficient of Friction

Coefficient of friction (N) is the proportionality factor giving the relationship between friction force (f) and normal force (N) (usually due to gravity) $u = \frac{f}{N}$.

The magnitude of the coefficient of friction depends upon N the nature of the materials in contact with each other. As an example, if the frictional force is 2500 lbs. and the weight of the vehicle is 2500 lbs., the coefficient of friction would equal 1.0. In actual conditions where an aircraft wreckage has skidded over the ground, it would be possible to determine the coefficient of friction by measuring the amount of force required to drag the wreckage, dividing that by the actual weight of the wreckage. It should be noted that the coefficient would be different for static friction and sliding friction, but in determining a crash deceleration the sliding friction would be of interest. For example: if a helicopter weighing 10 000 lbs. has skidded across a field, it would be possible to drag the helicopter wreckage across the same terrain and measure the amount of force required and, therefore, determine the coefficient of friction.

To know or to be able to estimate the coefficient of friction becomes very useful in application of the following two equations.

$$V_o = \sqrt{2gNS}$$

$$V_f = \sqrt{V_o^2 - 2gNS}$$

Example Problem: An 8000 lb. helicopter flies horizontally through a clump of trees as shown in Figure 11-12 and skids an additional 39 feet before stopping. Find the pulse shape, peak G, and pulse duration.

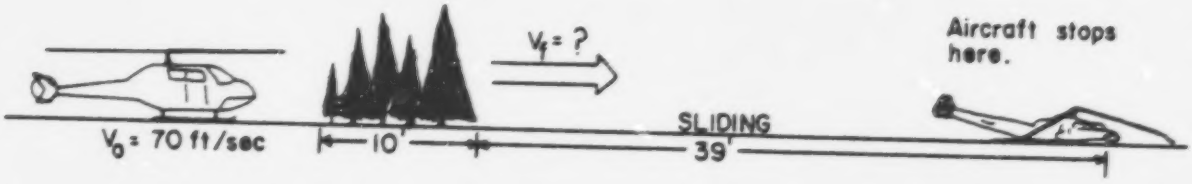


Fig. 11-12

SOLUTION: It must be noted that the main pulse occurs in the first 10 feet, therefore, V_f is not equal to 0. Unfortunately, V_f is unknown in this and must therefore be computed. If the average coefficient of friction during the 39 feet of sliding is estimated to be 1.0, the equation $V_f = 2gN\,S$ can be applied. Therefore, $V_f = \sqrt{2 \times 32.2 \times 1 \times 39} = \sqrt{2500} = 50$ feet per sec. It can be assumed that the pulse shape would be equivalent to triangular pulse type 3 and, therefore,

$$G = \frac{4V_o^2 - 2V_oV_f^2}{96.6S}$$

Therefore G = 7.8

Energy Absorption

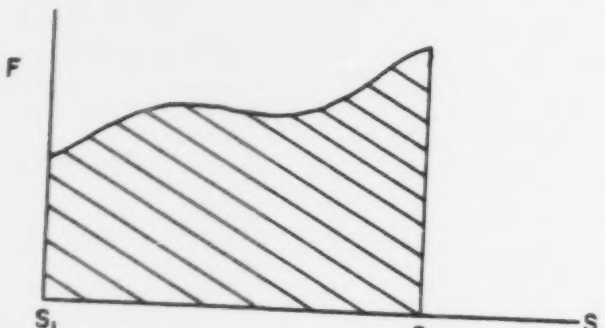
The application of energy absorption techniques is becoming increasingly more important in the protection of crewmen in aircraft. Seats, restraining systems, landing gears, and even the aircraft structure itself have been designed utilizing these techniques. The accident investigator therefore requires a basic understanding of the concepts of energy and energy absorbing principles. This understanding permits him to evaluate energy absorption techniques and recommend their use where appropriate evidence so indicates.

The concept of energy arises in the so-called energy principle which is derived from Newton's Second Law. This law states that if a net force acts on a body, the body will be accelerated; the magnitude of the acceleration is proportional to the magnitude of the force, and the direction of the acceleration is in the direction of the force.

When a single force acts upon a body an acceleration results. The body is accelerated in the direction in which the force acts. The magnitude of the acceleration is proportional to the magnitude of the force and to some quality of the body which has not yet been specified. Since both force and acceleration are vector quantities, Newton's Second Law may be written in the form of an equation:

$F = Ma$ where M = mass

Figure 11-13 shows a Force Displacement Curve where force F moves the mass through distance S.



FORCE DISPLACEMENT CURVE

Fig. 11-13

The area under the FS curve in Figure 9-13 is equal to the amount of work done, which is also equal to the change in kinetic energy (kinetic energy = $1/2\ MV^2$) therefore work = KE2 - KE1 = KE. This shows that the only way in which energy can be removed from a body (by reducing its velocity) is to hold a force on the body as the body moves. This might be done by employing a crushable structure or

material resulting in a force displacement curve such as that shown in Figure 11-14, which is typical of that of honeycomb materials.

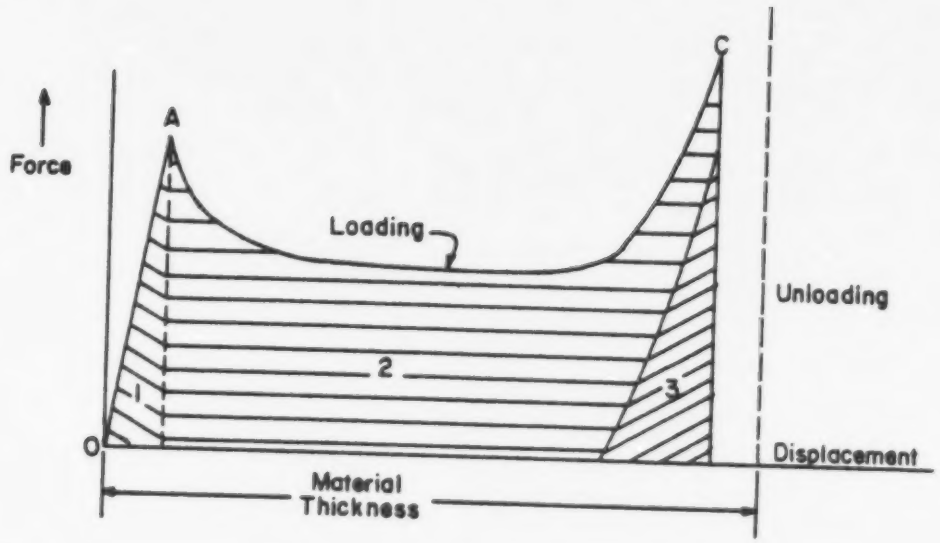


Fig. 11-14

A force displacement curve for an ideal energy absorber is shown in Figure 11-15. In this curve, the velocity is reduced with a constant deceleration and if A is constant then F = MA is constant.

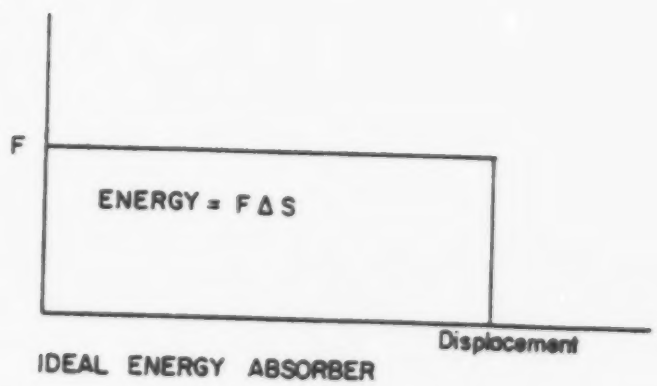


Fig. 11-15

Some materials such as honeycomb and certain foam materials approach this ideal force displacement curve, as shown in Figure 11-14. The area under the curve represents the total energy absorbed, but as unloading occurs, the energy of area 3 is given back in the form of rebound. Loading in the area of the curve between B and C is often referred to as "bottoming", a condition in which the deforming structure or material has become compacted, and the load increases rapidly with very little increase deformation. In some situations, the small peak area at A can be eliminated by precrushing the material to some extent.

Figure 11-16 shows a force displacement curve of the type which may be found in materials which have a high rebound characteristic, such as foam rubber. It should be noted that the total energy is returned during rebound, thus making this type of material undesirable as an energy absorber.

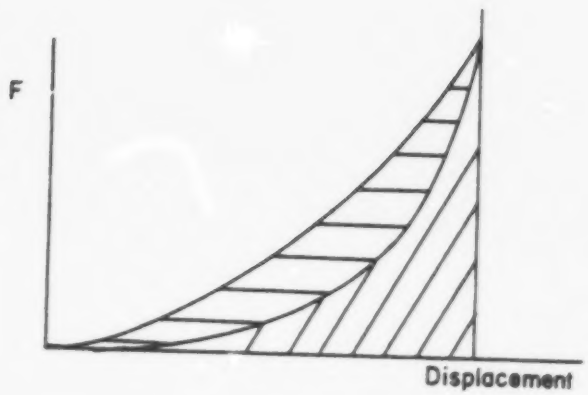


Fig. 11-16

CHAPTER XII

SURVIVABILITY OF HELICOPTER ACCIDENTS

"Passengers can be and are safely carried by airplanes, and as many as seven passengers have been carried at one time. As a rule these trips were made merely for the novelty of the experience, but on several occasions doctors found airplanes of the greatest value when compelled to travel a long distance at utmost speed. As airplanes rapidly travel from sixty to seventy-five miles an hour, and can travel a straight line from place to place, they can transport a passenger or mail with the utmost dispatch, when required.

"In wartime airplanes also played quite an important part, and, whereas their true value in warfare was questioned until really tested, they have now proved to be of great use in actual hostilities. To be sure an airplane is now and again struck with a shell and brought to earth, but even if the operator is killed the loss of a single machine and operator in this way is of no great importance as compared with the service rendered. Moreover, the falling airplane, or even the falling aviator, may kill or disable a number of the enemy, and in a way a dead aviator or a crippled machine is far more dangerous to life and limb than one flying overhead."

Harper's Aircraft Book 1913

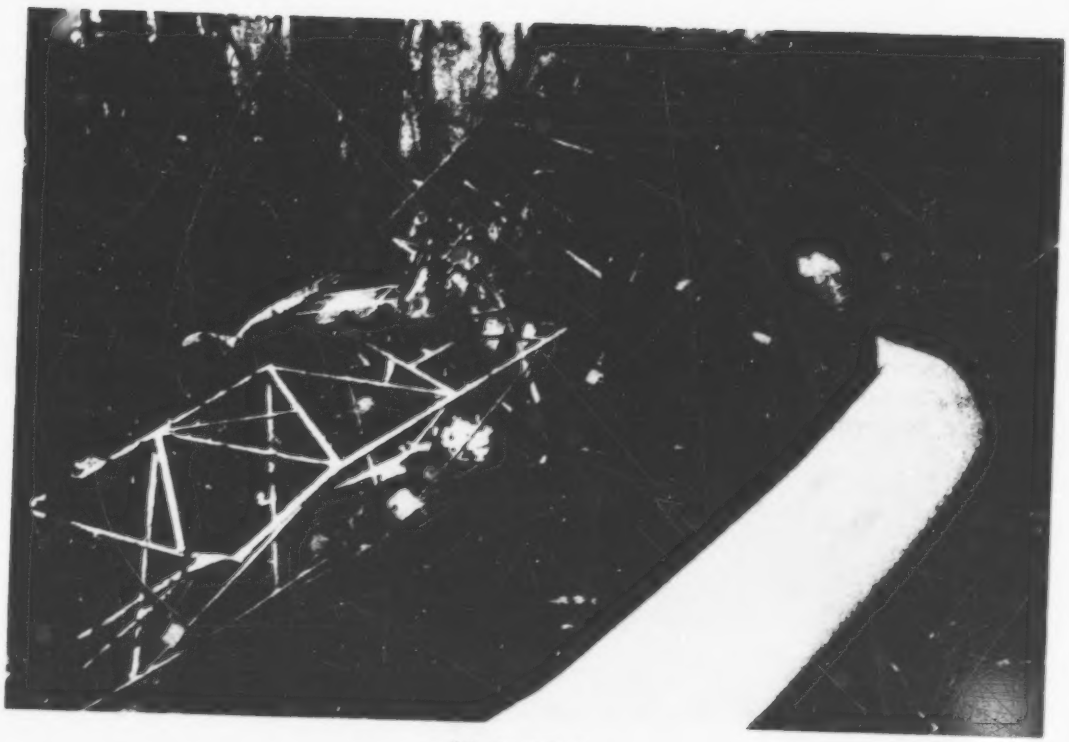


Photo 12-1

Obviously aircraft performance has improved markedly since this passage was written. However, particularly with respect to civilian aircraft, it would appear that little attention has been devoted to life support systems other than to restrain the aviator in the machine to prevent him from falling out during violent manoeuvers. Happily, this is not the case with military helicopters, where, thanks to the effort of many dedicated researchers, the pilot's chances of surviving an impact have increased considerably over the past few years. However, many helicopters in both the armed forces and civilian inventories are of older designs, and are not fitted with some of the more contemporary crashworthiness features.

The utopian situation in flight safety is a zero accident rate in any flying operation and many organizations devote much time and energy in trying to achieve this. However, even with the best training and the most sophisticated equipment accidents may occur as a result of a failure somewhere within the system. Therefore, the importance of better crashworthy design cannot be over emphasized. There are few things so tragic as loss of life where loss of life need not have occurred.

Crashworthiness, as mentioned in Chapter 11, may be defined as "the ability of basic aircraft structure to provide protection to occupants during survivable impact conditions. Impact conditions are considered survivable in that part of the cockpit cabin area where the crash forces are within the limits of human tolerance and where surrounding structure remains reasonably intact." Although the crash force in most accidents is applied in a direction oblique to the flight path, it is customary to resolve vertical and horizontal components of the crash force resultant and relate these to the human tolerance levels, either parallel or transverse to the spine. A normally seated person, when effectively restrained, can tolerate with minimal or no injury approximately forty-three G transfers to the spine, twenty-five G parallel to the spine in the foot to head direction (positive G), fifteen G parallel to the spine in the head to foot direction (negative G), and twenty G side to side (lateral as summarized in Figure 12-1.

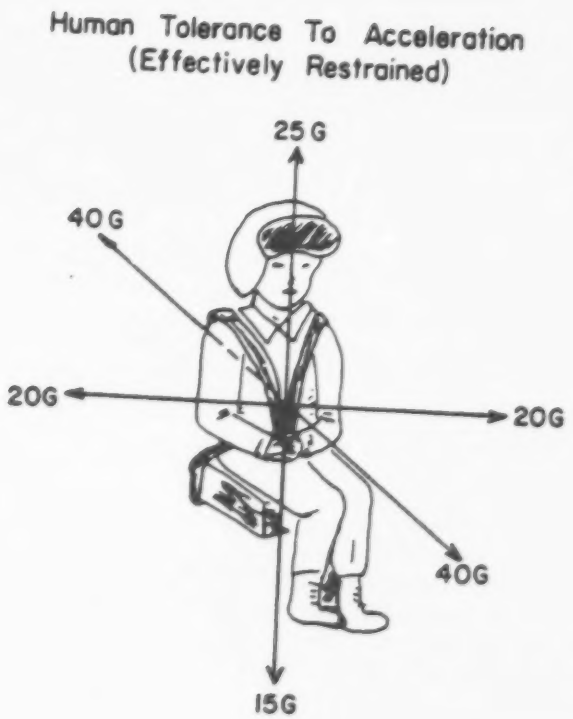


Fig. 12-1

Human tolerance data obtained from analysis of survivable accidents in the U.S. military, plus additional experimental data, show that tolerance is a function not only of the acceleration level and rate of application but also of duration. For this reason, it is not possible to completely define tolerance in terms of a single G value and duration. The methods of evaluating the severity of the environment, in terms of human tolerance, involve calculating a number, through mathematical treatment, that has several variables, then empirically relating the number to human injury. This number is referred to as an injury or severity index.

The data given in Figure 12-1 represents one limiting loading condition. It must be borne in mind that there are an infinite number of other conditions that will produce injury, including both higher G levels for shorter durations and lower G levels for longer durations. However, these limits are presented in this over-simplified fashion for general and comparative use.

Tolerance Limits to Positive (Headward) Acceleration

The human tolerance limit for headward acceleration is a pulse of approximately 0.1 seconds. Injuries, primarily compression fractures of spinal vertebrae, occasionally will occur at this level. These fractures may not be of such a nature as to cause incapacitation and thus may not interfere with one's ability to extract oneself from a helicopter. Tolerance to vertical impact loads is greatly reduced when the spinal column is in a flexed position or is misaligned laterally. For this reason a properly shaped seat back and an efficient shoulder harness restraining the occupant against the seat back are important factors in tolerance to headward acceleration.

Tolerance Limits to Anterior Posterior Acceleration

For spineward acceleration the human tolerance limit is approximately 45 G for a duration of 0.1 second or 25 G for a duration of 0.2 seconds. The human tolerance limit for sternumward acceleration has not been accurately established, but it can be safely assumed that the tolerance is greater than for a spineward acceleration. In one experimental situation a maximum of 83 G with a base duration of 0.04 seconds was experienced in a backward facing seat, resulting in extreme debilitation and shock to the subject who required emergency medical treatment. Human tolerance to sternumward acceleration therefore probably falls somewhere between this figure of 83 G for 0.04 seconds and 45 G for 0.1 seconds.

Tolerance Limits to Lateral Acceleration

Though very little research has been performed on human tolerance to lateral acceleration, in one particular experiment, volunteers were able to endure a pulse with an average G of approximately 11.5 for a duration of approximately 0.1 seconds without suffering any permanent physiological changes. It may be that the human survival limit is at some point beyond this level, possibly twenty G for 0.1 seconds.

Head Impact and Whiplash

Concussion is an important aspect of human tolerability to acceleration and can temporarily immobilize an individual, thus reducing his chances of survival by subjecting him to postcrash hazards. Experiments indicate that approximately 50 per cent of the potential for brain injury, in an impact to the unprotected head, is directly proportional to head rotation and inversely proportional to head translation resulting from the impact, while the other 50 per cent is directly proportional to the contact phenomena of the impact.

Rotary Wing Impact Conditions

Perhaps the most noteworthy conditions existing in a rotary winged impact are the marked downward component of its acceleration, cockpit penetration, and fire hazard due to the close proximity of flammables to ignition sources.

Vertical Velocity Changes

In studies performed on actual aircraft crashes, both in controlled and non-controlled environments, it was found that the median in the distribution curve for vertical velocity changes was approximately 24 feet per second, with one-half of the accidents involving vertical velocity changes greater than this and one half lower than this figure. For reference, 24 feet per second is the velocity reached by a body during the freefall of 8 feet 11 inches. Ninety-five per cent of the accidents incurred vertical velocity changes of less than 42 feet per second, which would correspond to a freefall of 27 feet 5 inches.

Longitudinal Velocity Changes

In a similar fashion the distribution of longitudinal velocity changes incurred in survivable accidents involving substantial structural damage and/or occupant injury was plotted. It was found that the median point represented a velocity change of approximately 28 feet per second with the velocity changes of one-half the accidents greater than this and one-half lower than this figure. Ninety-five per cent of the accidents occurred with longitudinal velocity changes of less than 50 feet per second.

Lateral Velocity Changes

The lateral velocity changes occurring in aircraft accidents have not been as well studied as vertical and longitudinal changes; however, recent work indicates that 30 feet per second is a realistic figure for rotary winged aircraft.

Combined Velocity Changes

The resultant velocity change of combined longitudinal, vertical, and later components in 95 per cent of survivable accidents of rotary and light fixed aircraft does not appear to exceed 50 feet per second.

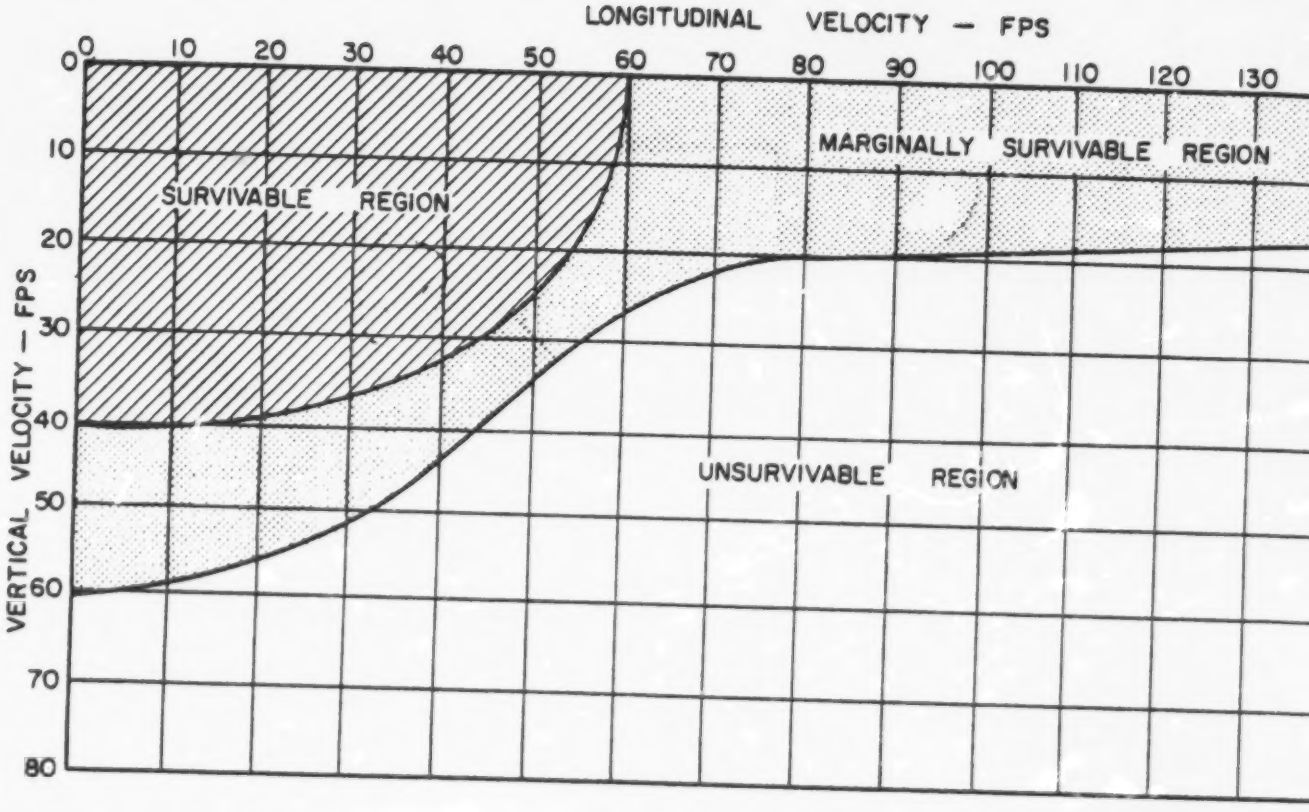


Fig. 12-2

The major factors that affect occupant survival as related to velocity changes in a crash are:

1. Initial impact velocity.

2. Velocity change in the major impact pulse.

3. Magnitude, rate of onset, and duration of occupant acceleration during the major impact pulse.

4. Direction of the acceleration with respect to passenger orientation.

Figure 12-2 summarizes the results of an analysis of actual accident experience based on accident case histories of military and civilian aircraft. There are but few severe survivable aircraft accidents in which the crash consists of only a single impact. Most crashes involve a major impact, in which the most severe conditions develop, followed by one or more secondary impacts. Usually, if a helicopter can withstand the major impact, then there is a good probability that the structure will provide protection throughout the remaining secondary impacts. If the fuselage

collapses under the crashload, the occupants may be crushed directly, released from restraint and then traumatized and/or trapped within the wreckage. In order to protect against this, the fuselage structure should be capable of absorbing, without loss of liveable space, approximately 50 per cent of the initial impact kinetic energy for velocities up to the normal approach speed for the particular helicopter type. Some of the energy may be absorbed through friction between the aircraft and the impact surface, and through deformation of structures in areas away from the occupiable volume of the aircraft.

In a study performed by Haley, et al, on accidents involving 71 utility helicopters, it was found that of the 434 people on board, more than half received injuries of a degree less than major; while almost one-third received major injuries from both thermal and impact causes; 9.4 per cent of the occupants were killed by impact and 6.4 per cent were killed by fire. Postcrash fires increased the incidence of death by a factor of two. Figure 12-3 illustrates events occurring during the 71 utility helicopter accidents. It should be noted that the last six conditions resulted in occupant injuries.

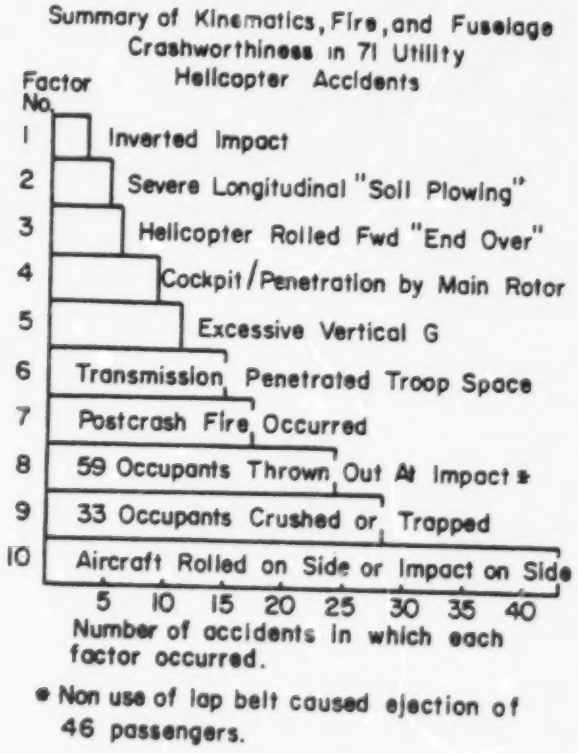

Summary of Kinematics, Fire, and Fuselage Crashworthiness in 71 Utility Helicopter Accidents
Factor No.
1 Inverted Impact
2 Severe Longitudinal "Soil Plowing"
3 Helicopter Rolled Fwd "End Over"
4 Cockpit/Penetration by Main Rotor
5 Excessive Vertical G
6 Transmission Penetrated Troop Space
7 Postcrash Fire Occurred
8 59 Occupants Thrown Out At Impact *
9 33 Occupants Crushed or Trapped
10 Aircraft Rolled on Side or Impact on Side
5 10 15 20 25 30 35 40
Number of accidents in which each factor occurred.
* Non use of lap belt caused ejection of 46 passengers.

Fig. 12-3

CREEP FACTORS

During the investigation of survivability of a helicopter accident, again, a systematized approach should be used. Through their years of experience evaluating the major threats to survivability in aircraft accidents, teachers at the Crash Survival Investigators School at Arizona State University have defined the following CREEP factors to provide a systematized approach to the investigation of survivability; or; in advance of an accident, a systematized approach in evaluation of crashworthiness of a given aircraft.

The CREEP factors are as follows:

C - container

R - restraints

E - environment

E - energy absorption

P - postcrash factors

a. escape

b. fire

Each of these will be discussed in turn.

Container

The container or occupiable volume of the helicopter should be evaluated with respect to soil plowing tendencies, energy absorbing properties of the structural members, and ability to maintain volume during the deceleration.

An important concept is that little sacrifice must be made in terms of weight to provide better crashworthy design. Rather than actually strengthening fuselage members, the ideal is to absorb energy from an impact in a predictable, controllable fashion. For this, various load limiting devices and members, made of ductile material, provide an advantage. The shape of the fuselage cross-section is also of importance. Haley has shown that the circular cross-section type of structure offers much more resistance to crushing in an impact as compared to a rectangular type structure. Little imagination is required to appreciate that if a square box is dropped on its corner it will probably fracture, whereas if a barrel is dropped from the same height it will probably remain intact. The ideal design for the cross-section of a helicopter fuselage, therefore, would be circular or egg-shaped with load-limiting devices between the belly and the floor of the aircraft to absorb energy before it is transmitted to the occupant. The energy absorbable material might be honeycomb material or ductile longitudinal beams in the floor.

The following recommendations regarding improved fuselage design for occupant protection are derived from the Crash Survival Design guide:

1. Helicopters should be designed to withstand lateral impact on a rigid surface such as concrete with a velocity change of 30 feet per second. The aircraft should provide the required degree of protection for crashes in which the fuselage rotates plus or minus 20 about its yaw axis.

2. In vertical impacts of rotary winged aircraft, almost all of the kinetic energy on impact is absorbed in fuselage and landing gear structure. Considering this, the aircraft should be designed to withstand vertical crashes onto a rigid surface with impact velocity changes of 42 feet per second. The aircraft should provide the required degree of protection for crashes in which the fuselage rotates plus or minus 15 about its pitch axis and plus or minus 30 about its roll axis.

3. Rotary winged aircraft should be designed to withstand a crash containing a 50 foot per second resultant velocity change. This pulse includes all combinations of longitudinal and vertical components vectorially summing to 50 feet per second or less, with vertical velocity components up to and including 42 feet per second. It includes all combinations of longitudinal and lateral components vectorially summing to 50 feet per second or less with lateral components up to and including 30 feet per second.

4. In order to provide living space for the crew members during some reasonable frontal crash environment, rotary wing aircraft should be designed to withstand a longitudinal impact into a rigid wall or barrier with an impact velocity change of 20 feet per second.

5. The fuselage and landing gear should be so constructed that the effect of terrain contact after antitorque loss is minimized; specifically, helicopters should be designed to impact sod type of terrain at 60 knots airspeed, 8 feet per second sinkspeed, 20° yaw, 10° roll, and 20° nose-up pitch without turning over. Should the helicopter turn over under these conditions the fuselage container should remain essentially intact for a minimum of two 360° rolls.

The indices of crashworthiness which have been proposed include:

(a) the degree of cabin collapse;

(b) the level of deceleration experienced by occupants during the crash.

To increase fuselage crashworthiness, and meet the above criteria, the following changes should be made:

1. Increase the energy absorption capacity of the structure surrounding the occupiable areas.

2. Modify structures such as the antitorque rotor tail boom etc., to ensure that if these parts fail they fail safely.

3. Reinforce the cockpit and cabin structure.

4. Modify the fuselage structure to allow increased deformation or collapse of structures in unoccupied areas.

Now that he is armed with the above information concerning the weaknesses in present crashworthy design of fuselage structure, the investigator can evaluate each of these factors in turn, with a view to either supporting recommendations or proposing new recommendations regarding improved design.

RESTRAINT SYSTEMS

Statistics from civilian helicopter accidents indicate that restraint system failure is a frequent cause of injury and fatality. The author has observed the tragic consequences of inadequate systems on many occasions.

This is truly unfortunate because body restraint is relatively easy to establish and can mean the difference between life and death. To verify this, consider the frequency of fatal head injuries or the fact that evacuation from a burning or sinking aircraft is obviously enhanced if no prior injury or debilitation has occurred.

According to the Crash Survival Design Guide, restraint harnesses for personnel and cargo should provide the restraint necessary to prevent injuries to all aircraft occupants in crash conditions approaching the upper limits of survivability. Numerous methods of restraining the human body have been proposed, and while some of these have been exceptionally good, some have left much to be desired. There are certain qualities, however, that a harness should possess if it is to be used routinely:

1. The harness should be comfortable and light in weight.

2. The harness should be easy for the occupant to put on and take off.

3. The harness should contain a single point release system, easy to operate with one (either) hand since a debilitated person might have difficulty releasing more than one buckle with a specific hand. It should also be protected from inadvertant release.

4. The harness should provide freedom of movement to operate the controls of the aircraft. This requirement often necessitates the use of an interia reel in conjunction with the shoulder harness.

5. The harness should provide sufficient restraint in all directions to prevent injury due to decelerative forces in a potentially survivable crash.

Lap Belt Anchorage

The actual anchorage point for the lap belt can be located either on the seat bucket itself or on the basic airframe structure. If located on the airframe, consideration must be given to the movement of the seat when load limiting devices are used in order that the lap restraint remains effective. In this situation, however, the belt strength properties must be adequate to restrain the motion of the seat, as well as the occupant.

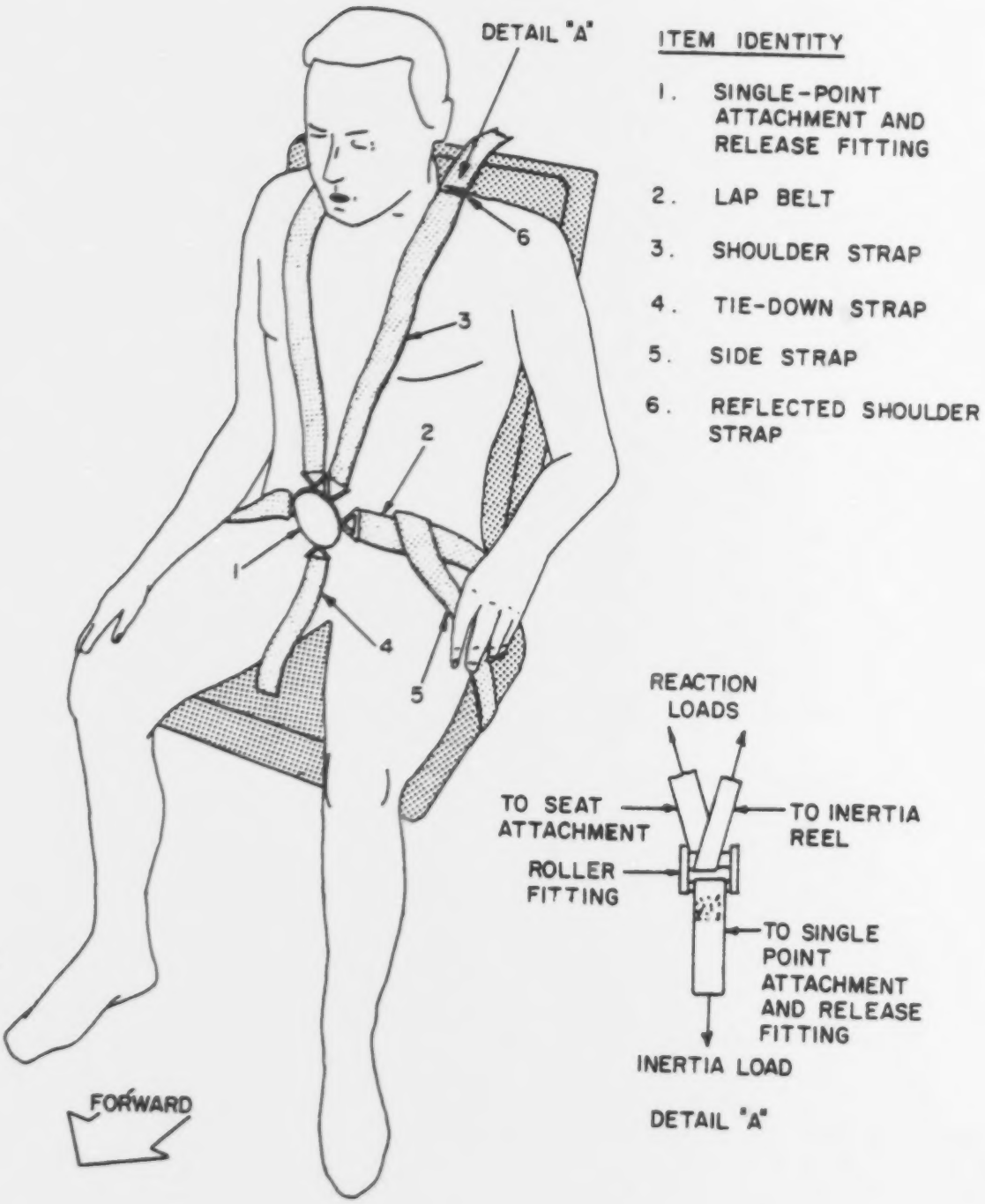

DETAIL "A"
ITEM IDENTITY
1. SINGLE-POINT ATTACHMENT AND RELEASE FITTING
2. LAP BELT
3. SHOULDER STRAP
4. TIE-DOWN STRAP
5. SIDE STRAP
6. REFLECTED SHOULDER STRAP
FORWARD
REACTION LOADS
TO SEAT ATTACHMENT
TO INERTIA REEL
ROLLER FITTING
TO SINGLE POINT ATTACHMENT AND RELEASE FITTING
INERTIA LOAD
DETAIL "A"

Fig. 12-4

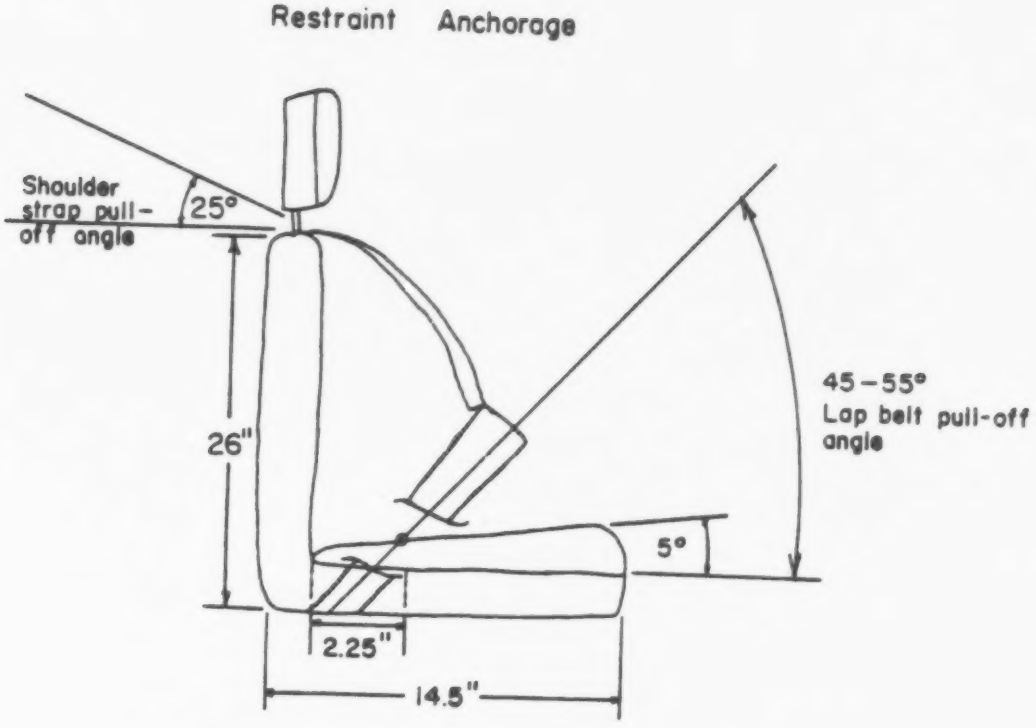


Fig. 12-5

The lap belt should be anchored so that it provides optimum restraint for the lower torso when subjected to longitudinal decelerations. Figure 12-5 shows the optimum lap belt angle which will hold the belt on the iliac crests and prevent submarining during the crash deceleration. A belt tie-down strap or crotch strap attached to the centre of the lap belt will prevent upward belt movement which causes the belt to be pulled off the iliac crest and into the abdomen resulting in injury to abdomenal viscera. Figure 12-4 illustrates an ideal system which meets all of the criteria.

Inertia Reels

An inertia reel installed in the restraint system provides freedom of movement to operate the controls of the aircraft and improves comfort while allowing for automatically locking the shoulder harness during an abrupt deceleration. The freedom of movement is obtained by spring loading the reel cable or webbing, which allows extension without apparent restraint. The United States Military uses two types of reels - the impact sensitive type and the rate of extension type. The older impact sensitive type takes a two to three G impact on the inertia reel housing itself to lock automatically. Normal flight loads will not activate this reel. The "rate of extension" type reel operation depends on the rate at which the harness is pulled out,

a function of the direction. This system can be checked at any time by giving a jerk to the shoulder harness itself. The United States Military specifications require that both reel types lock automatically before the occupant travels more than half an inch during an emergency deceleration. Accident statistics indicate that rotary-winged aircraft frequently impact on their sides or impact vertically with little longitudinal deceleration. It is, therefore, recommended that all rotary-winged craft should incorporate the "rate of extension" type reel.

Various materials have been tested for webbing load capabilities and elongation. It has been recommended that materials with minimum elastic stretching be used to reduce the effects of dynamic overshoot where rebounding of the material may increase the final G loading on the occupant. As examples of materials tested, dacron will elongate by approximately 13 per cent, whereas nylon will elongate by 28 per cent. The flamability of the material should also be considered.

The ideal width for a lap belt is 2 1/4 inches, with a thickness of at least 1/10th of an inch. The shoulder belt, although it can be constructed of a thinner material, should have a two-inch width.

Several points of advice which will improve the pilot's chance of surviving an accident are:

1. Use the restraints.

2. The restraints should have a convenient locking device.

3. Thin webbing should be replaced on shoulder straps.

4. Excessive widths for shoulder strap guides should be eliminated (the shoulder strap guide width should be no greater than 3 inches.

5. Brief all passengers on the use of restraint systems.

Litter Restraint Harnesses

Due to the increased use of helicopters for emergency medical evacuations, consideration must be given to the difficulties in restraining personnel in litters. Restraint with existing systems is compromised due to the absence of built-in restrictions to transverse movement. Lateral movements may be controlled by strapping a patient to a rigid litter frame, but longitudinal movements require control with a complex harness. At present, it appears that the use of two straps, two inches wide, wrapped around the litter will offer restraint, compatible with the anchoring systems of litters at present employed in helicopters. These wrap-around straps should sustain a 4000 pound loop load (2000 pounds for straight pull). Two of these straps should thus provide restraint for a 30 G loading when some allowance is made for unequal loading and dynamic overshoot.

estraint Anchorage

In all too many cases the author has observed belts of adequate strength tied down to materials which had little more effectiveness than tinfoil. Careful consideration must be given to lap belt and shoulder harness tie down points in an aircraft as the chain is only as strong as its weakest link.

One area which has escaped the legislator's pen, at least on civvy street, is the seat back height. At present there are no laid-down requirements concerning the height of the seat back even though low seat backs may result in injuries. For example, one manufacturer installs as standard equipment a low seat back, the idea being that rear seat passengers will have better visibility forward and also feel more at home with the crew. A high seat back is a relatively expensive option.

An accident involving one of these machines illustrates the point. Impact following an autorotation resulted in a high vertical "G" loading, but, in addition, the pilot jacknifed rearwards resulting in a direct compression of his spine from behind. The following x-rays illustrate the rather severe nature of the injuries to bony structure, with resultant damage to the cord itself.

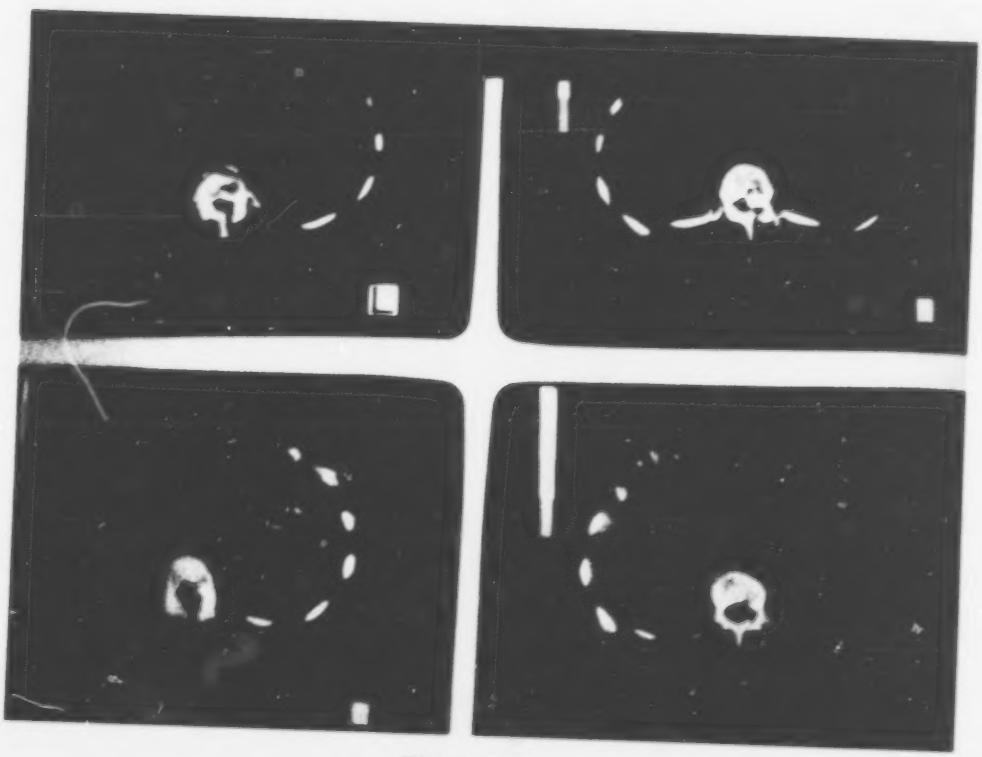


Photo 12-2

Environment

The kinematics of body action associated with the aircraft crash impacts are extremely violent. Although flailing of the body parts is much more pronounced where a lap belt only is utilized, multi-directional flailing of the head, arms, and legs is quite considerable even with a proper shoulder restraint system. Space for occupants is usually at a premium in helicopters. It is usually not feasible to remove items such as structural members which may become involved in impacts with bodily parts during a deceleration. Some steps must be taken therefore to minimize the injury potential by redesign and by careful application of padding, and in some cases by the use of additional protective equipment such as helmets. The environmental hazards in general consist of primary, secondary and tertiary hazards:

1. Primary Hazards

   Primary environmental hazards are those rigid or semi-rigid structural members within the extremity envelope of the head and chest.

2. Secondary Hazards

   Secondary environmental hazards are those that could result in trapping or injuring the lower extremities to the extent that one's ability to escape rapidly would be compromised.

3. Tertiary Hazards

   Tertiary environmental hazards are those rigid and semi-rigid structural members that could cause injury to flailing upper limbs to an extent that could reduce one's ability to operate escape hatches or perform other essential tasks.

Much work has been done in the past 10 years to improving and reducing the lethal environment in automobiles by modifying such structures as dashboards, protruding objects, knobs, and padding the dashboard with impact absorbing materials. Unfortunately for the aircraft pilot and passengers, an equivalent amount of redesign has not been applied to the lethal environment of the cockpit.

Head Impacts

Protective helmets and/or energy absorbing structures in the occupant's immediate environment is considered essential, since under certain circumstances even the forces incurred in a minor crash could cause unacceptably high head impact velocities. Studies conducted by Dynamic Science at Wayne State University indicate that head impacts onto rigid surfaces at more than 20 feet per second cannot be readily tolerated by humans without an appreciable amount of energy absorbing material. Use of suitable energy absorbing padding materials, breakaway panels, or ductile materials in high hazard areas in the cockpit will reduce the injury potential of the cockpit area.

Hazards to Lower Extremities

Potential hazards to lower extremities are of two general types:

1. The most hazardous consists of the sharp unyielding structure of lower instrument panels typical of many aircraft.

2. The other consists of rudder pedals that are designed in the form of a bar and offer no support for the heel, or are designed in such a way that the foot can be driven between the rudder pedals or under the rudder pedals and trapped.

The first type of hazard causes a very frequent injury pattern consisting of factures of the tibia and fibula or "Spitfire" injuries. This may be corrected by using suitable materials and systems as outlined above, within the lower leg strike envelope.

The second type of hazard results, for example, with bar-type rudder pedals, when the heel is forced under the pedal during an impact, or in other designs, when the foot is trapped between the pedals and other structures or between the pedals themselves. It has been recommended that the pedals be a maximum of 2 inches apart and a maximum of 2 inches from adjoining structures, or, if this is not possible, a minimum of 6 inches apart and a minimum of 6 inches from other structures. This would minimize the "bear-trap" effect. Photo 12-4 shows a typical installation.

At present much work has been done on the application of impact absorbable materials such as rate sensitive foams in cockpit padding. Materials now being tested include foamed sulphur and polyurethane foamed plastic. The criteria for adoption of padding is oultined in the Crash Survival Design Guide, and it is worth noting that the U.S. Department of Transportation is proposing the adoption of padding criteria for motor vehicles which is slightly more stringent from the standpoint of energy absorption. Physical properties other than stress and strain, which must be taken into consideration, include odour, resistance to chemicals and solvents, and flammability properties. One extremely important aspect which must be considered is the formation of toxic gases and byproducts during oxidation in fire.

Energy Absorption

The modification of the helicopter fuselage to improve energy absorption properties and the influence on fuselage shape on this has been discussed previously, and may be found in greater detail in the Crash Survival Design Guide. Improvement of fuselage energy absorption capabilities need not necessarily mean a sacrifice in weight, as components may be designed to deform in a controlled and predictable way, and load limiting devices such as longeron supports may be utilized. Ideally, the cabin area can be strengthened to some extent as long as the materials used are not excessively brittle or easily fractured, resulting in further environmental hazards. Using the principles of crash kinematics for determining the G loading on occupants, it is obvious that the G loadings are directionally proportional to the square of the velocity at impact and inversely proportional to the stopping distance. Since the velocity at impact can often not be controlled, the only controllable variable therefore is stopping distance (S). Aside from deformation of the fuselage itself, the

only other main modification is in the application of these principles to the occupant's seat. Therefore, the utilization of energy-absorbing materials in seat cushions, for example, and loading limiting devices becomes important.

A multitude of devices have been proposed, developed and tested for absorbing energy and limiting loads. As shown in the previous Chapter the kinetic energy of the moving mass may be absorbed by applying a force over a distance; this is the primary mechanism for absorbing crash energy. Energy absorbing mechanisms should stroke at loads tolerable to human occupants and should provide stroke distances consistant with these loads and with the energy to be absorbed. Various studies have shown that plastic deformation of materials, primarily metal, results in a reasonably efficient energy-absorbing process, and consequently most load limiting or energy absorbing devices use this principle. The criteria for efficient energy absorbers are as follows:

1. The device should provide a predictable force versus deformation trace.

2. The rapid loading rate expected in crashes should not cause significant change in the force versus deformation characteristics of the device.

3. The assembly in which the device is used should have the ability to sustain tension and compression.

4. The device should be as light and small as possible.

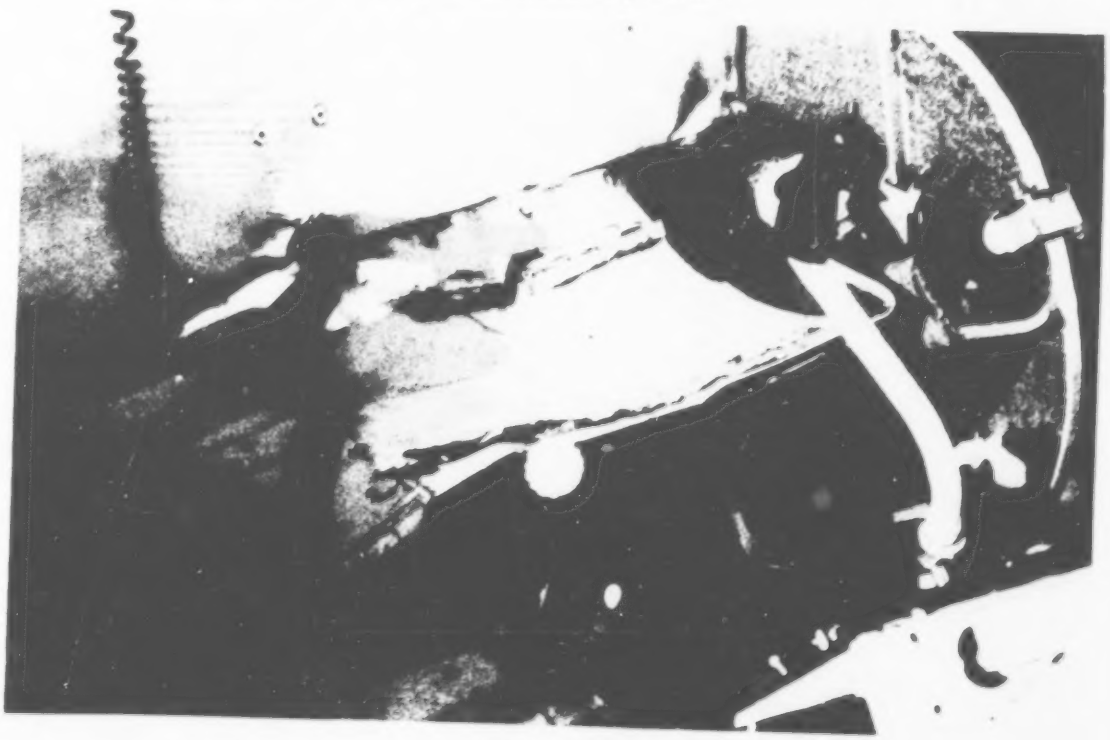


Photo 12-3

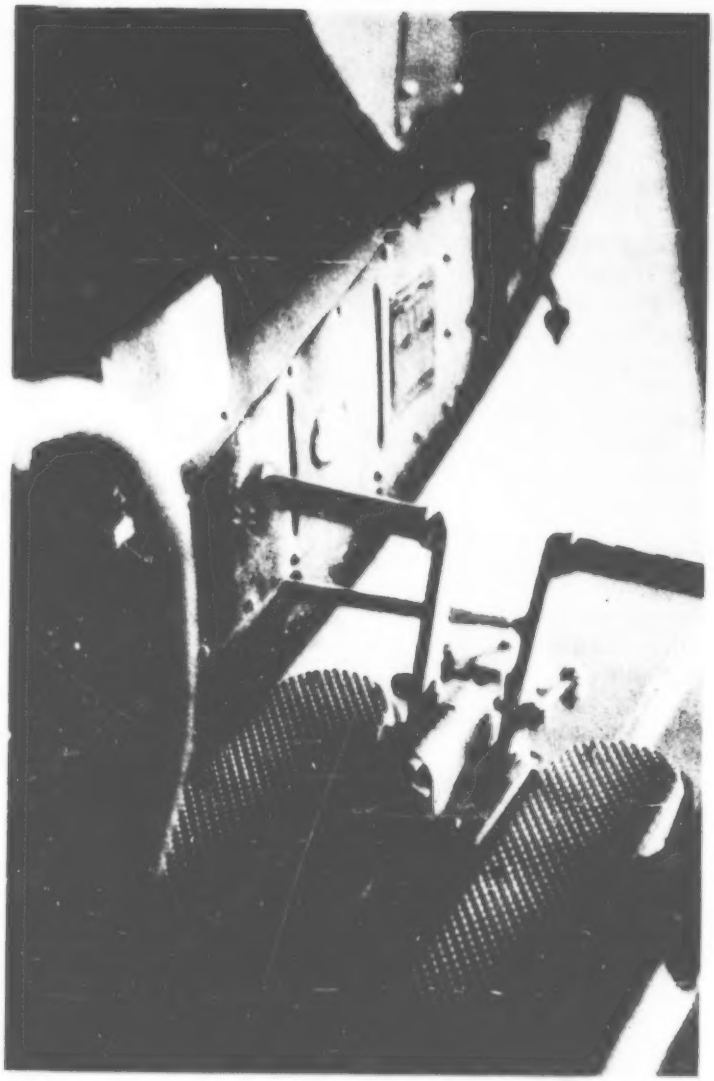


Photo 12-4

5. The device should be economical.

6. The device should be capable of being relied upon to perform satisfactorily throughout the life of the aircraft without requiring maintenance.

One type of device which has been extensively tested is an aluminum tube which inverts when loaded. This tube was first developed for use in automobile steering wheels and was used as a front seat compression leg for an airliner seat in experimental seat tests for N.A.S.A. It provided a vertical deformation of 5.5 inches at a controlled load and although lateral forces caused the inverting tube to be distorted from a circular to an elliptical shape the device still performed satisfactorily. Honeycomb materials have also been tested and the force displacement curve has already been illustrated in the previous Chapter.

Special attention must be paid to the seat cushions in helicopters; these should not only provide comfort and vibration damping for the pilot but also must be capable of absorbing vertical energy in impact situations. The material certainly should not increase the decelerative levels to the pilot's spine due to dynamic overshoot as a result of elastic rebound. For this reason foam cushions are not recommended. More suitable materials such as those described under energy absorption, or even styrofoam should be employed in the construction of seat cushions. The author recommends that in helicopters which have not employed load-limiting devices, or where important structures are found beneath the seatpan, that these aircraft be retrofitted with cushions manufactured of energy absorbing materials. Photograph 12.3 shows the seatpan design commonly used in helicopters. It is obvious from the photograph that the seatpan was subjected to a high vertical load and although deformation is evident, much can be done to improve the energy-absorbing capability of this type of seat.

Photos 12-5 and 12-6 show actual load meter recording of drop test done by the author some years ago. Note the attenuation provided by an energy-absorbing foam - the peak G is roughly one-quarter when the foam is used. The area under the two curves is identical, indicating that the same amount of energy was absorbed in each case.

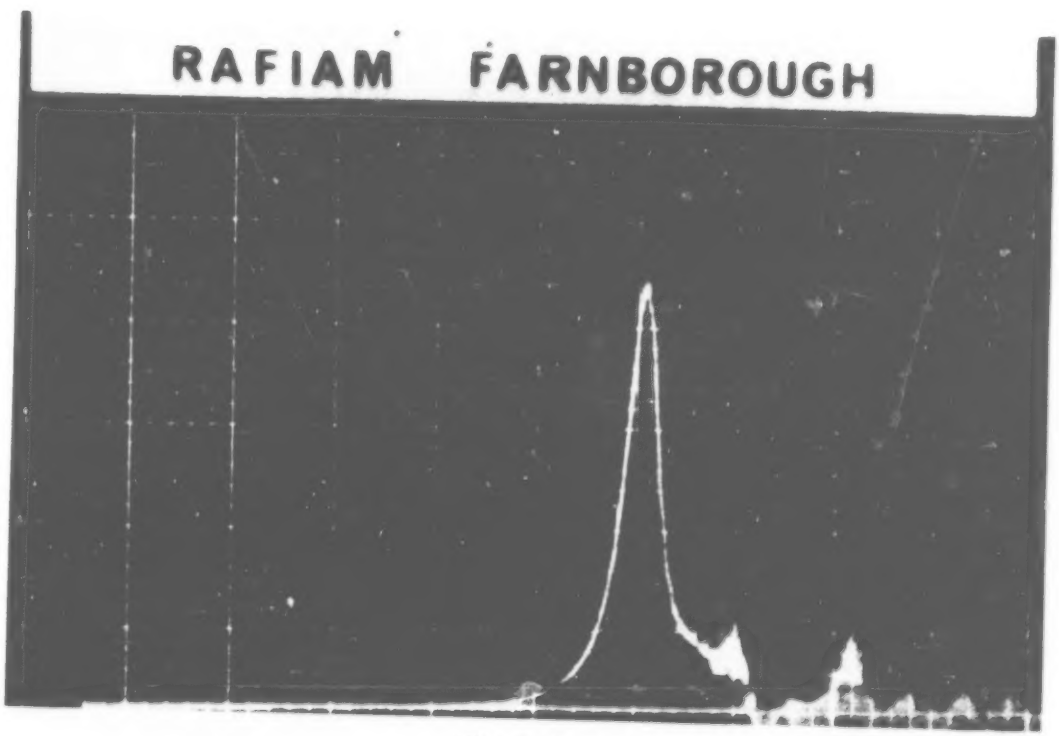


Photo 12-5

Structural Connections

There is, of course, no use applying energy-absorbing devices in a seat if the seat breaks away during an impact. Attention must be given to the anchorage of the seat. The seat must be able to remain affixed to the floor or other structures of the aircraft during deformation of these structures, and the attachment fittings should be of adequate strength (certainly not castings) and design to be capable of withstanding bending and flexing of the floor.

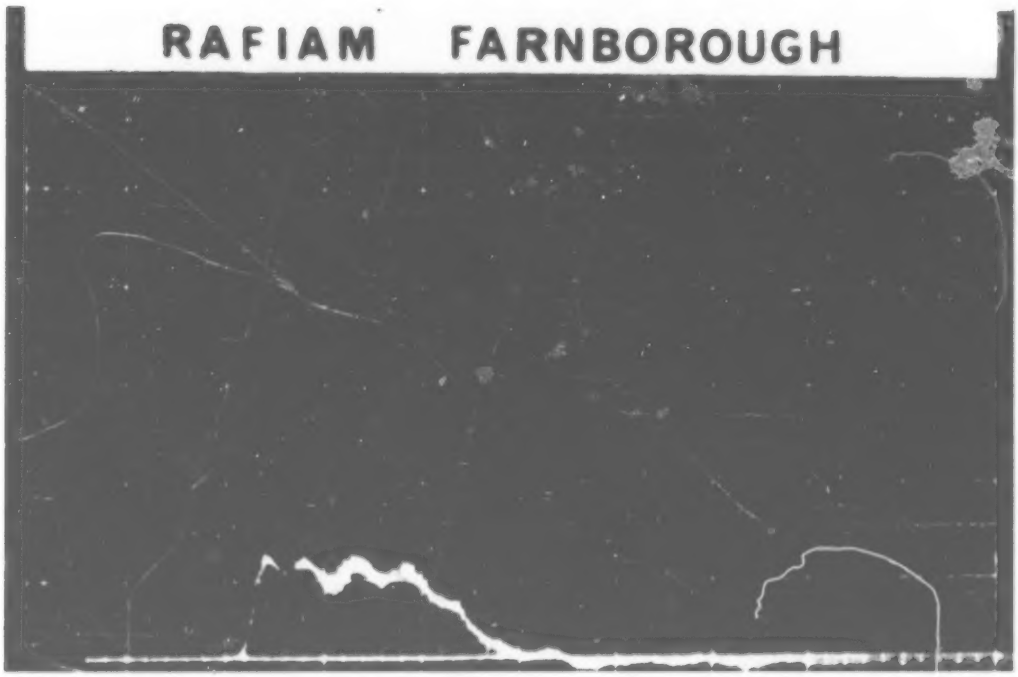


Photo 12-6

Post-Crash Factors

These vital factors affecting survivability in an accident, although relegated to the last part of the discussion of CREEP factors, are certainly not the least important, particularly in helicopters, where in some types, the hazard of fire is extreme.

Emergency Escape

Because of the postcrash fire hazards in helicopters and the fact that the majority of injuries and fatalities that occur from all types of accidents are forms of thermal injuries, emergency escape provisions should be thought of primarily in terms of the post-crash fire threat. The major considerations when dealing with emergency escape consist of emergency exits themselves, access to the emergency exits, and emergency lighting, particularly in larger cargo and passenger carrying helicopters. It must be remembered that the post-crash environment is usually very confusing, frightening, and that panic may be a major factor, particularly if a post-crash fire occurs.

The Crash Survivable Design Guide classifies exits into three categories:

(a) Class A Exit: Doors, hatches, canopies or other exit closures intended primarily for normal entry and exit.

(b) Class B Exit: Door, hatches or other exit closures intended primarily for service of logistic purposes.

(c) Class C Exit: A window, door, hatch or other exit closure intended primarily for emergency evacuation.

Exit enclosures for Class C exits must be capable of being removed from the exit opening within five seconds regardless of the aircraft's attitude. This Class constitutes the minimum requirement for an emergency exit. A Class A exit with emergency jettison provisions is normally considered to be superior to a Class C exit.

It has been recommended that Class C exits should be at least 22 inches square, with six-inch radius corners which allows evacuation at the rate of 1.5 seconds per man. If with a particular helicopter, the design does not lend itself to an exit of this size and shape an alternate size and shape can be used providing that the exit can handle a large man dressed in winter flight or field clothing at the rate of 1.5 seconds per man. For helicopters with a single crew position one Class A exit and one Class C exit on the opposite of the cockpit should be provided, assuming that a sliding or clam shell type canopy is not used. The rationale for this is to provide an alternative means of escape if the aircraft rolls on its side and an exit becomes blocked. With side by side crew position cockpits, at least two Class C exits should be provided, one on each side of the fuselage. With this arrangement any combination of Class C and Class A exists may be substituted provided the Class A exits have an emergency jettison feature. With tandem crew position helicopters such as the Huey Cobra, the minimum requirements should be two Class C exits and one Class A exit with an emergency release provision, assuming that the two crew positions are mutually accessible. This means that a 99 percentile crew member dressed in winter flight clothing could, without undue difficulty, climb from one crew position to the other in order to exit the aircraft in an emergency. The minimum emergency escape exit requirement for the passenger sections should be two Class C exits, one exit installed on each side of fuselage. In helicopters with engines, transmissions, major controls etc., located over personnel compartments bottom and/or aft, exits could be substituted for overhead exits.

Exits intended for emergencies should be equally divided on each side of the aircraft and, if feasible, should not be directly opposite each other because of the probability of crowding in one particular area. In addition, the exits should be such as to be exposed to the least distortion and to provide maximum accessibility to occupants following a crash. They should be located as far away from external hazards such as propellers, turbine engine inlets, armament, etc., and as far away from fuel spillage areas and from major ignition sources as possible. All exits used for the emergency exit should be capable of being opened by rescue personnel from outside of the aircraft. The release should be designed so that it can be opened quickly from the inside or the outside by one person using one hand, and no secondary operations such as moving or unlocking locks, catches, stops, bolts, etc., is necessary. The exit release handles should be located in such a manner that they will not snag clothing and so that it is not necessary for crew members to unlock their shoulder harnesses in order to turn the handles. This is important primarily because it is sometimes desirable to release emergency exists prior to crash impact, as in water crash landings. All crew members and passengers should be briefed before take-off on operation of the exits, and the method of removal should be obvious and natural to all persons on board the aircraft.

Access from aisles to all types of exits must be provided so that the exits will not be obstructed by any seats, litter installations, etc. In helicopters with a wide fuselage, such as the Chinook, problems have been encountered when the helicoper is lying on its side, in reaching an exit on the other side as the height of the exit may be beyond the reach of the occupants in the aircraft.

Emergency Lighting

Emergency lighting capable of being operated manually or activated automatically at impact should be provided for reading exit operating instructions and for lighting the exterior of the aircraft to illuminate exits and paths of escape and to serve as a crash locator beacon. Experimentation by N.A.S.A. and other agencies has shown that following an aircraft crash the air immediately becomes contaminated with dust and/or smoke leading to disorientation of the passengers which would likely result in panic. Emergency lighting, therefore, can become critical. Emergency lighting power sources should be independent of the main electrical system of the helicopter and should sustain effective illumination for at least fifteen minutes.

Post-Crash Fire

Studies of accident records indicate that the greatest number of fatalities occur in accidents involving post-crash fire. In helicopters, post-crash fire is a major threat due partly to the tendency for flammables and ignition sources to be located in close proximity as a result of centre of gravity limitations. It must be borne in mind that aviation fuel does not constitute the only combustion hazard and that oil and hydraulic fluid may be responsible for initiation of the post-crash fire if ignition sources are present. Although oil and hydraulic fluid is difficult to light in puddles the mists or vapours are highly flammable and often substances such as lubricating oil are preheated as a result of normal aircraft operation. In addition, hydraulic fluid is usually under pressure and, should a hydraulic line be severed, a highly inflammable or explosive mist may result. In the investigation of a fire accident, combustible

TOXIC GASES PRODUCED BY BURNING AIRCRAFT MATERIALS (In Addition to CO and CO_2)										
ITEM	HCl	SO_2	BENZENE	UNSATURATED HYDROCARBONS	NO_2	HCn	Cl_2	ARSINE	PHOSGENE	HF
ACRYLIC	←			NONE						→
LATEX FOAM	X	X	X	X						
LEATHER		X			X	X	X			
MINERAL WOOL					X					
MODACRYLIC	X	X		X		X				
POLYURETHANE FOAM				X						
PLYWOOD				X				X		
SIMULATED LEATHER				X					X	
VINYL FOAM			X	X						
WOOL		X				X				
POLYVINYL FLUORIDE	X									X
URETHANE						X				
ABS						X				
POLYSULFONE		X								
RUBBER		X								

Fig. 12-6

cargo also must be considered. Upholstery, although not usually the primary ignition source, decreases the burn-through times of the fuselage due to its insulating properties and provides a good flame path for fire propagation.

The ignition sources in a post-crash fire consist of:

1. Flames:

   Flames may provide the primary ignition sources and the result in engines or from oil hydraulics.

2. Hot Surfaces:

   These include brakes, heaters, bulbs, inverters, nickel-cadmium batteries, etc.

3. Electrical Sparks:

4. Friction Sparks:

5. Static Sparks.

Many studies have been performed where aircraft and helicopters were crashed and allowed to burn. In these studies it was found that the time taken to reach the limits of human tolerability, based on the respiratory heat tolerance of 390 Fahrenheit, was around 120 seconds for large passenger or cargo fixed-wing aircraft, and varied between 6 to 15 seconds for utility-cargo type helicopters.

The human tolerability in post-crash fire depends upon two factors:

1. Heat

2. Toxic gases resulting as by-products of combustion. The most obvious toxic by-product of combustion is carbon monoxide. A carboxyhemoglobin percentage of 35% is sufficient to produce disorientation, collapse, and fainting and could be considered a tolerance limit as far as escape from a burning aircraft is concerned. A level of 60 per cent can result in unconsciousness, respiratory failure, and death in long-term exposure. Forbes, Sargeant and Roughton, in a paper in the American Journal of Physiology stated the following:

   $COHB = K \times CO \times T$

   is the percentage of carboxyhemoglobin formed,

   CO = the percentage of carbon monoxide in the air,

   T = exposure time in minutes,

   K = absorption constant.

The absorption constant K depends upon the ventilation rate of the exposed persons. The constant K is equal to 3 for persons at rest, 5 for light activity, 8 for light work, and 11 for heavy work. A likely value for K during a post-crash escape is 8. Therefore, an individual will reach the escape limiting 35 per cent COHB level when he breathes 3.0 per cent carbon monoxide for 90 seconds.

Table 12.6 shows the toxic gases produced by burning aircraft materials in addition to carbon monoxide and carbon dioxide. It is, therefore, obvious that careful consideration must be given when choosing materials for upholstery, seat cushions, etc.

Research into preventing post-crash fires or cutting down on the severity of post-crash fires has followed three main lines:

1. Modified fuels.

2. Fuel inerting systems.

3. Crashworthy fuel containment systems.

Various types of modified fuels have been tried. The main principle in modifying a fuel to improve the chances of preventing a post-crash fire is to increase its viscosity so that it will not be spilled and flow around the crash site as a liquid would. However, by increasing the viscosity there are several disadvantages. Obviously to be used as a fuel, high viscosity material must be reconverted to a fluid state. In addition, studies have shown that the more viscous fuel tends to be thrown a longer distance at an impact and, additionally, tends to cling to surfaces much like napalm does.

The rationale behind fuel inerting systems is elimination of oxygen, which is required for combustion, from the areas surrounding the combustile materials. Therefore, such designs as nitrogen inerting systems, where nitrogen is released in the area, have been tried. Although these systems work well in a laboratory environment in reality at a crash site, there is often wind and other factors which displace the inerting gas and a fire could then result as, particularly in the case of turbine engines, the parts may remain hot enough to result in ignition of flammables for as long as twenty minutes.

The most promising system at present is the crashworthy fuel system whereby the fuel is contained and not allowed to spill in the first place. Perhaps a combination of these systems would provide a further margin of safety in post-crash fires. That the crashworthy fuel system is effective is illustrated by the vast reduction of postcrash fires in United States Army UH 1 Huey helicopters. In a personal communication with the author, Dr Harry Robertson of Arizona State University mentioned that in some 2000 U.S. Huey accidents, both in combat zones and in other operations, there have only been about seven post-crash fires, none of these resulting in injury to the occupants.

The Crashworthy Fuel System

The ideal fuel system is one which completely contains its flammable fluids both during and after the accident. To accomplish this it is necessary that all components of the system, including fuel tanks and fittings, flammable fluid lines, fuel transfer system components, and vent systems, be properly designed with crashworthiness in mind.

The location of a flammable fuel-carrying tank in an aircraft is of considerable importance in minimizing the post-crash fire hazard. The location must be considered with respect to occupants, ignition sources, and probable impact areas. Greater distance between occupants and the fuel supply tends to increase the escape time because it reduces the likelihood of fuel entering the occupant's area. Although it is not always feasible to keep the fuel away from a probable ignition source, tanks should not be installed in or over the engine compartment, or near the battery, or other primary ignition sources. Another important consideration is to locate tanks away from areas of maximal impact damage, such as around landing gears, etc. Location of fuel tanks under the helicopter floor poses a serious threat because of the propensity towards accidents in near level flight altitudes at high sink speeds. As much aircraft structure as possible should be allowed to crush before the tanks themselves are exposed to direct contact with obstructions. In addition, expansion areas around the tank should be provided into which the tank and its contents may displace.

As far as tank shape is concerned, a cylindrical or rectangular shape appears to be the best choice as these shapes can displace easily without snagging. The tank should be constructed of the self-sealing, puncture resistant materials used in many military aircraft.

Failure of the fuel cells is often caused by ripping out of fuel cell fittings, such as fillers and crossover fittings, allowing a tear in the tank wall to initiate. Attachments that are normally used to support the fuel cell in the aircraft, and attachment of the various tank components, such as the filler neck and the boost pump, must be designed in such a way that breakaway occurs under high loadings. A self-sealing valve should be employed in each of the fittings.

Damage to fluid lines frequently causes spillage in aircraft accidents. These are usually cut by surrounding structure or worn through by abrading against rough surfaces. The use of flexible hose, armoured with a steel braided harness, is strongly suggested in areas where this is a threat. In addition, the routing of hoses should be carefully considered during the design stage. Fuel lines should be routed along the heavier structural members and away from sources of ignition such as electrical wiring. Another important item in the fuel transfer system is the boost pump, which plays a major role in the initiation of the crash fire sequence. The majority of boost pumps in use today are installed in the fuel tank and are rigidly bolted to the tank and to the aircraft structure. Crash damage to the pump can cause fuel spillage and also supply electrical sparks for ignition of the fuel. Air-driven boost pumps and engine-mounted suction type boost pumps are alternate solutions that are much less hazardous. If design requirements dictate that a boost pump be installed in the fuel

tank it would be better to use an air-driven pump. The pump should be bolted only to the fuel cell unless a frangible attachment is used.

In addition to providing for improved containment of fuel, some control of ignition sources should be considered when designing helicopters. As early as possible during the crash sequence the fuel, oil and hydraulic lines should be closed off at the engine firewall and the fuel should also be cut off as close as possible to the point of induction into the engine.

The electrical system in an aircraft is a potential crash fire ignition source because it is extensively distributed throughout the aircraft and because of the large amount of energy present, compared with the small amount actually required to produce fire ignition under ideal conditions. For example, the common incandescent filament in a landing light is hot enough to ignite fuel 0.75 - 1.50 seconds after the bulb breakage. The ignition potential of the aircraft's electrical system may be reduced by modification of the electrical system to provide for removing from the electrical circuits all electrical generation or storage sources before, or during the early phases of the crash sequence, and by controlling component location in the environment.

Additional protection can be provided by installation of fuel baffles, fire curtains, drip fences, and fuel flow diverters.

CHAPTER XIII

HELICOPTER CRASH SURVIVABILITY RATING GUIDE

Now that some of the fundamentals of survivability are understood, it becomes painfully obvious that there are many shortcomings in the designs of helicopters in present inventories. The American and Canadian Armed Forces have, to some extent, modified their specification criteria in order to operate with vehicles possessing a higher survivability potential, but many of the improvements, such as crashworthy fuel systems, have not yet been installed in civilian aircraft. Perhaps lack of consumer awareness is the main villain in this apparent apathy regarding survivability, for, surely, when the demand exists, the manufacturer makes an effort to satisfy the consumer.

Be that as it may, many of the readers will be in a position to evaluate and criticize present designs and make recommendations regarding these deficiencies. Therefore, with the kind permission of Dr. James Turnbow and Dr. Harry Robertson of the Crash Survival Investigator's School at Arizona State University, the following Crash Survivability Rating Guide is included.

Rotary-Wing Crash Survivability Rating

When evaluating any aircraft with respect to crash survival there are six basic factors that should be considered. These are (1) Crew Retention System; (2) Troop Retention System; (3) Post-Crash Fire Potential; (4) Basic Airframe Crashworthiness; (5) Evacuation; and (6) Injurious Environment.

In order to develop a reasonable Crash Survivability Rating, weighted values have been assigned to the various factors. The per cent weight assigned to each is based on their relative hazard potential. The six factors along with their hazard potential are as follows:

		Hazard Potential	Optimum Number	Actual Value
1.	Crew Retention System	17.92%	130	
2.	Troop Retention System	17.23%	125	
3.	Post-crash Fire Potential	35.19%	255	
4.	Basic Airframe Crashworthiness	17.23%	125	
5.	Evacuation	8.29%	60	
6.	Injurious Environment	4.14%	30	
	TOTALS	100.00%	725	

To make the job of rating easier, the hazard potential percentage has been converted to an optimum numerical value where a perfect score on all six factors would equal 725. For existing aircraft inadequate restraint system and post-crash fire have been equally responsible for injuries and fatalities in accidents and therefore, were weighted at approximately 35% each. A poor score on either of these important items could indicate a critical situation in the event of a crash - depending on such variables as number of personnel carried, operating terrain, and rescue facilities.

Each of the six factors is in turn broken into sub-factors against which a hazard potential percentage has been assigned and converted to an optimum numerical value. The person conducting the evaluation simply selects that portion of the optimum numerical value that each sub-factor is worth and lists it opposite the optimum value in the space provided under "Actual Value".

CREW RETENTION SYSTEM RATING

	Optimum Number	Actual Value
	Rotary-Wing	
Vertical Energy Absorption Capacity	30	
Restraint Webbing Geometry and Strength	20	
Seat Longitudinal Strength	10	
Seat Lateral Strength	10	
Seat Vertical Strength	10	
Absence of Casting in Stressed Areas	10	
Shoulder Strap Guide Width	10	
Shoulder Strap Pull-Off Angle	5	
Lap Belt Angle to Seat Cushion	5	
Lap Belt Tiedown Strap	5	
Inertia Reel Type	5	
Depth of Structure Between Floor and Belly	10	
Total Points	130	

TROOP RETENTION SYSTEM RATING

	Optimum Number	Actual Value
	Rotary-Wing	
Vertical Energy Absorption Capacity	30	
Restraint Webbing Geometry and Strength	20	
Seat Longitudinal Strength	10	
Seat Lateral Strength	10	
Seat Vertical Strength	10	
Absence of Casting in Stressed Areas	10	
Shoulder Strap Pull-Off Angle	10	
Lap Belt Angle to Seat Cushion	10	
Lap Belt or Side Tiedown Strap	5	
Depth of Structure Between Floor and Belly	10	
Total Points	125	

POST-CRASH FIRE POTENTIAL RATING

	Optimum Number	Actual Value
Spillage Control		
Fuel containment	60**	
Oil containment	20	
Flammable fluid lines	30	
Firewall 9		
Fuel flow interruptors	9	
Ignition Control		
Induction and exhaust flame location	30	
Location of hot metals and shielding	30	
Engine location and tiedown strength	15	
Battery location and tiedown strength	12	
Electrical wire routing	12	
Boost pump location and tiedown strength	7	
Inverter location and tiedown strength	6	
Generator location and tiedown strength	6	
Lights location and tiedown strength	5	
Antenna location and tiedown strength	4	
Total Points	255	

** If a range extension system is included in the evaluation, allow 40 points for primary fuel and 20 points for the range extension system.

BASIC AIRFRAME CRASHWORTHINESS RATING

	Optimum Number	Actual Value
	Rotary-Wing	
Distance from Nose to Troop/Passenger area	10	
Absence of "Plowing" Tendency	15	
Resistance to Longitudinal Impact Loads	15	
Resistance to Vertical Impact Loads	30	
Resistance to Lateral and Roll-Over Impact Loads	30	
Landing Gear Vertical Force Attenuation	20	
Landing Gear Location	5	
Total Points	125	

EVACUATION RATING

	Optimum Number	Actual Value
Ease and reliability of exit operation	15	
Ratio of usable exits to occupants	15	
Identification of exits	10	
Availability of exits in rolled aircraft	10	
Emergency lighting	10	
Total Points	60	

INJURIOUS ENVIRONMENT RATING

	Optimum Number	Actual Value
Proximity of cockpit controls and other structure	10	
Retention of interior equipment	10	
Rudder pedal area	5	
Absence of injurious objects in cabin	5	
Total Points	30	

RATING SYSTEM CRITERIA

General

Each of the sub-factors listed previously are discussed briefly on the following pages. In rating an aircraft, the sub-factors should be given a point value proportional to the desirable qualities outlined in the discussion.

CREW RETENTION SYSTEM

Vertical Energy Absorption Capacity

Optimum = 30 points

Some method should be provided in the seat structure to attenuate vertical impact forces to a value of about 20G on the seat occupant. This decelerative loading must be maintained through a minimum stroke of eight inches in order to offer protection in the majority of fixed-wing aircraft accidents. If the energy-absorbing device is a fixed-load type, it should stroke at a load of approximately 3000 pounds. This value makes an allowance for the following parameters: (a) a 15-pound seat bucket weight; (b) only 80 per cent of total occupant weight rests on the seat; and (c) allowance for the 5th percentile (136- pound) pilot to ensure a 25G maximum deceleration.

A.	A seat bucket energy-absorber with a minimum 8-inch thickness	100%
B.	A crushable honeycomb, non-resilient cushion of minimum 4-inch thickness	40%
C.	A crushable, expanded foam cushion of a minimum 4-inch thickness	30%
D.	A slow-rebound expanded foam ("Ensolite" or "Ethafoam") of a minimum 4-inch thickness	20%
E.	Elastic foam rubber cushion or no attenuating material	0%

Restraint Webbing Geometry and Strength

Optimum = 20 points

All webbing should be a minimum of 0.09 inch thickness to ensure low elongation and minimum "creasing" under load. Padding material in the abdominal and collarbone area is desirable. The strength and width of the lap belt, shoulder strap, and tiedown strap are listed below:

Item	Width (In.)	Strength (LB)	
Lap belt	2.5	8000	(loop)
Shoulder straps	2.0	4000	total
Belt tiedown strap	1.5	2500	

Each of the above factors on restraint webbing can be rated as a per cent of the total points as follows:

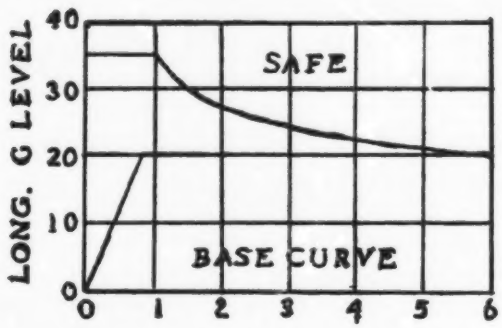
Webbing thickness	10%
Strength and width of lap belt	40%
Strength and width of shoulder straps	40%
Strength and width of belt tiedown strap	10%

The strength is more important than the width of the webbing; therefore, the number of points allowed should be proportional to the strength values.

Seat Longitudinal Strength

Fixed-wing Optimum = 15 points
Rotary-wing Optimum = 10 points

The desired G-level versus deformation is shown:



SEAT PAN DEFORMATION - IN.

Fig. 13-1

To be acceptable, a seat must have a load deflection curve which rises to the left and above the base curve and extends into the region beyond the upper curve. Load deflection curves must be obtained from static tests of the complete seat units.

Seal Lateral Strength

Optimum = 10 points

The desired G-level versus deformation is shown:

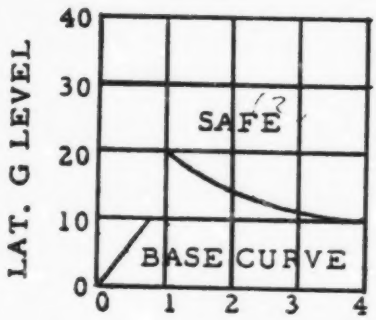


Fig. 13-2

Seat Vertical Strength

Optimum = 10 points

Since castings are noted for poor ductility, this item requires no explanation. If castings are used in two or more critically-stressed areas, the rating should be zero, unless it is known that the casting material has been treated to ensure ductility.

Shoulder Strap Guide Width

Optimum = 10 points

The width of the guide at the top of the seat back should not be more than 3.0 inches.

Shoulder Strap Pull-Off Angle

Optimum = 5 points

The shoulder strap guide should be located a minimum of 26 inches above the undeflected seat cushion. If the shoulder harness is connected to structure aft of the seat back, the angle of the strap with respect to the seat cushion should be between zero and 25 degrees upward, as illustrated.

*For each one inch of variance from the 26-inch dimension, 20 per cent should be deducted from the optimum score.

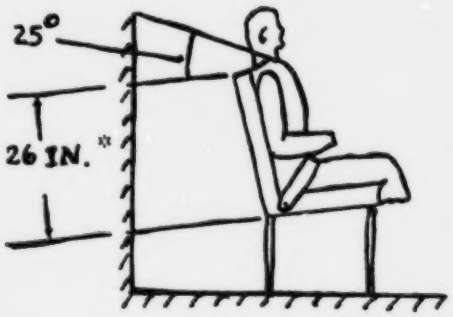


Fig. 13-3

Lap Belt Angle to Seat Cushion

Optimum = 5 points

The lap belt centreline should project an angle of 45-55 degrees to profile with respect to the seat cushion. This angle requires that the centreline be approximately 3 inches forward of the back seat and seat cushion intersection.

Lap Belt Tiedown Strap

Optimum = 5 points

The lap belt should be retained in place on the pelvis by some kind of tiedown strap. Preferably, the strap should be attached between the centre of the belt and the seat pan. A less optimum method consists of two straps attached at either side of the seat pan and the frontal portions of the lap belt. The side straps should be rated only half as effective as the centre tiedown straps.

Inertia Reel Type

Optimum = 5 points

All rotary-wing aircraft should utilize a rate-of-extension type reel only (MIL-R-8236, type MA-2, or MA-6). This type reel should be checked by a quick jerk to determine locking ability.

Depth of Crushable Structure Between Floor and Belly

Optimum = 10 points

A fuselage of circular cross-section with a crushable depth of two (2) feet minimum between the floor and the belly skin is ideal. If a flat belly structure is used, a higher celeration onset rate will result and less deformation will occur than with a circular fuselage. Thus, for two aircraft of equal crushable depth, the flat belly aircraft would be rated only half as much as the circular belly.

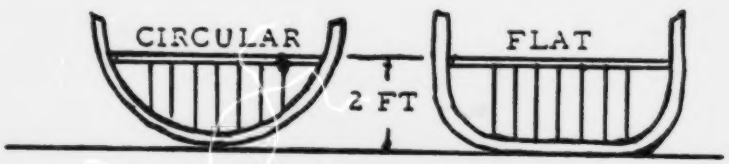


Fig. 13-4

TROOP RETENTION SYSTEM

The rating criteria for this section is identical to that for the Crew Retention System with some exceptions as noted:

Vertical Energy-Absorption Capacity

Optimum = 30 points

Same as Crew Retention Criteria.

Restraint Webbing Geometry and Strength

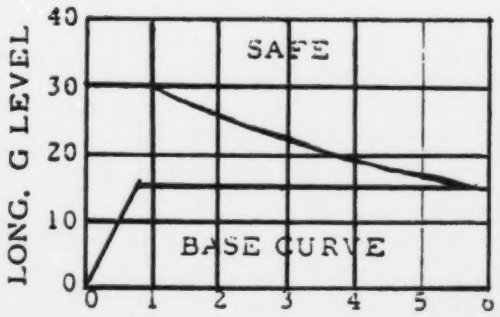
Optimum = 20 points

Same as Crew Retention Criteria, with exception that a side tiedown strap of 1500 pounds capacity can be used instead of a belt tiedown strap for side-facing personnel.

Seat Longitudinal Strength

Optimum = 10 points

The desired longitudinal G level versus deformation is shown:



SEAT PAN DEFORMATION - ON.

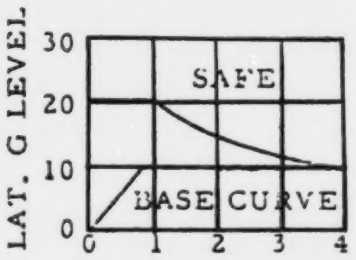
Fig. 13-5

It should be noted that this is a sideward loading on a side-facing seat.

Seat Lateral Strength

Optimum = 10 points

The desired G level versus deformation is shown:



LATERAL DEFLECTION - IN.

Fig. 13-6

Seat Vertical Strength
Same as Crew Retention Criteria.

Optimum = 10 points

Absence of Castings in Stressed Area
Same as Crew Retention Criteria.

Optimum = 10 points

Pull-Off Angle
Same as Crew Retention Criteria.

Optimum = 10 points

Lap Belt Angle to Seat Cushion
Same as Crew Retention Criteria.

Optimum = 10 points

Lap Belt or Side Tiedown Strap
Same as Crew Retention Criteria with the exception that a side tiedown strap is equally acceptable with a centre belt tiedown for side-facing troops.

Optimum = 5 points

Depth of Structure Between Floor and Belly
Same as Crew Retention Criteria.

Optimum = 10 points

POST-CRASH FIRE POTENTIAL RATING

Spillage Central

Optimum = 60 points

Fuel Containment

Location (20% of total value) - 12

The location of the fuel tank should be evaluated with respect to the anticipated impact area, occupiable area, large weight masses, and primary ignition sources.

Vulnerability (20% of total value) - 12

The vulnerability of a fuel tank should be evaluated with respect to possible tank ruptures caused by various aircraft structural failures, such as landing gear failure

and vertical column deflection. Tank failures associated with structural displacement, such as ruptures around the filler neck, the fuel line entry and exit area, the quantity indicators, and the tiedown devices should also be considered.

Construction Technique (50% of total value) - 30

The construction technique is evaluated for two primary considerations. One is tank geometry and the other is tank construction materials.

Tank Geometry - 10

Smooth contoured shapes are given the highest number of points, whereas irregular shapes and interconnected multicell tanks are given the lowest number of points.

Cell Material - j- 20

The tank is given a certain number of points, depending upon its construction.

1.	Cellular: tough wall material	20
2.	Cal. .50 bullet proof, self-sealing	10
3.	Cal. .30 bullet proof, self-sealing and crash resistant	10
4.	Pliecell	5
5.	Metal canister	2
6.	Integral	0

Fuel Boost System (10% of total value) - 6

The fuel boost pump should be evaluated according to its potential for causing fuel spillage due to fuel cell rupture or line failure. This includes location and method of fuel cell attachment.

Oil and Hydraulic Fluid Containment

Optimum = 20 points

Location (34% of total value) - 7

The location of the oil tank should be evaluated from the standpoint of its proximity to the anticipated impact area, occupiable area, large weight masses, and primary ignition sources.

Vulnerability (34% of total value) - 7

Evaluate from the standpoint of rupture resistance from other aircraft structures, e.g., control linkage failures causing puncture to the tank.

Construction and Tiedown Adequacy (43% of total value) - 6

Construction Methods - 3

Construction methods are evaluated in descending order of oil containing ability.

1. Cellular - 3 points

2. Bladder - 2 points

3. Sheet Metal - 1 point

Tiedown Adequacy

Tiedown should be evaluated primarily on the adequacy of the system to support the tank during typical crash acceleration.

Flammable Fluid Lines

Optimum = 30 points

Construction (33% of total value) - 10

The construction of fuel lines should be judged in accordance with the hose material and couplings. Experience has shown that rigid lines fail before the flexible type; thus, flexible lines with a steel braided outer sheath are given the most points. Also included in this phase of the evaluation are the couplings. The fewer the couplings the better. Ninety degree couplings are less desirable than the straight type. Any coupling is less desirable than an uncut hose. Aluminum fittings usually fail before steel ones.

Routing (33% of total value) - 10

The routing of the fuel lines is an important consideration. The lines must not pass through areas where they can get trapped, cut, or pulled. Extra hose length (20-30% in areas of anticipated structural deformation) should be provided. Holes through which the fuel lines pass should be considerably larger than the O.D. of the hose.

Breakaway Fittings (33% of total value) - 10

Breakaway fittings should be installed on each fuel line that enters and exits the fuel tank. It is also advisable to have them installed at strategic locations throughout the system.

Firewall

Optimum = 9 points

Evaluate the firewall from the standpoint of how well it will function as a shield between crash-induced fluid spillage and the various engine ignition sources.

Fuel Flow Interrupters

Optimum = 9 points

Fuel flow interrupters are devices that block or divert the flow of spilled flammable fluids. There are many different methods to perform this function; the fire curtain in the H-21 helicopter is a good example.

Ignition Control

Induction and Exhaust Flame Location

Optimum = 30 points

Evaluate from the standpoint of:

1. Location of expelled flames in relation to location of spilled flammable liquids.

2. Fuel ignition.

Location of Hot Metals and Shielding

Optimum = 30 points

Evaluate from the standpoint of how well the hot items (temperatures above 400° F) are shielded or protected from fuel spillage. Components included are:

Engine (external and internal)

Exhaust System

Heater

Engine Location and Tiedown Strength

Optimum = 15 points

Consider consequences of engine separation. Where will the engine go and how will it affect the fuel cell, exhaust system, electrical wiring, and fuel and oil lines? Will the engine come into contact with spilled flammable fluids?

Retention strength is more important for helicopters in which the engine may be located above or just behind the fuel cell; it is of less consequence for pod-mounted engines.

Battery Location and Tiedown Strength

Optimum = 12 points

Evaluate from the standpoint of tiedown strength and of vulnerability of the battery and attached wiring to damage during a crash. Location should also be as far as possible from fuel and oil tanks and anticipated areas of flammable fluid spillage.

Electrical Wire Routine

Optimum = 12 points

Evaluate from the standpoint of crashworthiness of routing and vulnerability to damage during crash. Some excess length (20-30%) should be provided to allow for airframe deformation during a crash.

Fuel Boost System

Optimum = 12 points

The fuel boost system should be evaluated with respect to its function as an ignition source. The following items should be considered:

Power Supply (An air pressure system is best, a hydraulic system is next best, and an electrical system is least desirable).
Pump Location (A suction system with the pump located on the engine is best. A pump located outside the tank is next best, and an internal tank mounted pump is least desirable).

Transformer-Rectifier and Tiedown Strength

Optimum = 6 points

Evaluate from the standpoint of tiedown strength and of vulnerability of the generator and attached wiring to damage during a crash. Location should be as far as possible from fuel and oil tanks and anticipated areas of flammable fluid spillage.

Generator Location and Tiedown Strength

Optimum = 6 points

Evaluate from the standpoint of tiedown strength and of vulnerability of the generator and attached wiring to damage during a crash. Location should be as far as possible from fuel and oil tanks and anticipated areas of flammable fluid spillage.

Lights (Beacon, Search and Navigation)

Optimum = 5 points

Are the light filament and/or wires immediately surrounding the light attachments in the area of possible flammable fluid spillage?

Antenna Location

Optimum = 4 points

Evaluate the antenna systems and their respective wiring from the standpoint of vulnerability to damage and location in areas of possible flammable fluid spillage.

BASIC AIRFRAME CRASHWORTHINESS

Distance from Nose to Troop/Passenger Area

Optimum = 10 points

This item will obviously affect the crashworthiness of any aircraft, whether rotary-wing or fixed-wing, as long as the crash force acts generally along the longitudinal axis. Thus, some method is needed to grossly evaluate the advantage of increased crushable structure forward of the front row of cabin seats. It is assumed that aerodynamic requirements as well as visibility requirements will continue to dictate that the crews of 200+ m.p.h. multi-engine aircraft will be located in the nose of the aircraft and that only a limited amount of crushable structure can be provided between them and the point of probable impact. Thus, the evaluation must be aimed at the cabin section where the majority of the aircraft occupants are located. For most general aviation type aircraft, the cockpit and cabin must be considered as one unit.

The amount of crushable structure ahead of the passengers should logically be related to the airport approach speed of the aircraft since most survivable accidents will occur at or less than this velocity. Thus, for an aircraft with a very slow stall/approach speed, the crushable structure needed can be less than for an aircraft with a very high approach/stall speed.

The optimum length of crushable structure or deforming distance can be calculated for various changes by using the formula:

$$d = \frac{V_2^2 - V_1^2}{64\,G}$$

where d = total deforming distance

V_2 = aircraft impact velocity - ft/sec

V_1 = aircraft velocity after major impact - ft/sec

G = fuselage crushing strength

Experimental test results indicated that a 20G fuselage crushing strength is reasonable value. It is assumed that about 75 per cent of fuselage structure is compressible longitudinally, while the remaining 25 per cent is "incompressible". For purposes of this gross calculation, it seems reasonable to further assume that the terrain deformation offsets the incompressible portion of the fuselage. Thus, the calculated deforming distance (d) is assumed to be the length of the aircraft from its nose to the first row of passenger/troop seats. The most severe crash is the complete stop from approach speed in a singlue pulse; for this situation, the term V_1 is zero and the desired distance (d) can be computed for various approach (impact) velocities.

Samples of crushing distances required are calculated below:

Impact Velocity (mph)	Impact Velocity (fps)	Crushable Distance Required (d) (feet)	
40-55	60-80	$V^2 = (70)^2\ 64\ (20)$	= 3.8
55-60	80-100		= 6.3
68-82	100-120		= 9.4
82-95	120-140		= 13.0
95-109	140-160		= 18.0
109-122	160-180		= 23.0
122-136	180-200		= 28.0
136-150	200-220		= 34.0

With the above values available as a guide, any aircraft can be grossly evaluated on a comparative basis with other aircraft.

Absence of "Plowing" Tendency

Optimum = 15 points

The primary objective here is obvious. The nose and belly of the aircraft should be smooth enough and have structural members of sufficient strength underneath to prevent it from plowing a furrow in the earth. The lower skin should be thick enough to resist tearing, thus providing a skidding surface for the aircraft.

Resistance to Longitudinal Impact Loads

Optimum = 15 points

The primary objective is to provide sufficient strength to prevent the roof of the aircraft from moving forward and downward with respect to the floor of the aircraft. Continuous beams running from the nose of the aircraft under the floor for the entire length of the occupied section is preferable since this type design will probably prevent the floor from buckling upward. If is obvious that enough wall structure must be available on either side of the aircraft to prevent collapse due to inadequate sheer strength. In this respect, a fuselage with many large openings is undesirable. All concentrated masses, which may become a hazard to occupant in a crash, should be restrained to a level of 20G.

Resistance to Vertical Impact Loads

Optimum = 30 points

The structure must be evaluated by its resistance to collapse due to vertical impact loads. This requires a simultaneous evaluation of resistance to longitudinal impact loads, since the resultant may be the critical loading. For example, the UH-LA helicopter might not come "unglued" by a purely vertical impact, but accident statistics indicate that a longitudinal load is usually present and the resultant load is the cause of the roof failure on this aircraft.

If the engine and transmission are located over the cabin or just aft of the cabin, it is recommended that the design tiedown strength be not less than 20G in the longitudinal and vertical directions to prevent cabin penetration. Regardless of

tiedown strength, the fuselage shell could contain peripheral frames at a spacing not to exceed 20 inches in order that a maximum amount of energy is absorbed before a mass will penetrate the structure.

This item will necessarily have to be evaluated in a gross manner; however, some pertinent design criteria are available. For example, the vertical strength of the fuselage shell is usually determined by the retention strength of the engine and rotor transmission, and their retention strength is stated in the aircraft model specification. For example, the Cayman UH-2 fuselage structure is designed to sustain a 20G downward loading from the engine and rotor transmission; thus, the fuselage is very strong.

Resistance to Lateral and Roll-over Impact Loads

General:

Evaluate in regard to the probability of cabin collapse during a roll-over or lateral impact. Even though the evaluation of this point is difficult, some design features will be obvious as discussed below:

Optimum = 30 points

When the entire side of the cabin consists of a door, as in the UH-1A aircraft, it is obvious that this structure will be very weak during a roll-over crash and it should be evaluated accordingly. As an extreme contrast, a circular fuselage with few large openings will have maximum integrity during a roll-over. All concentrated masses, which could become a hazard to occupants in a crash, should be restrained to a level of 15G. A 15G retention strength is always recommended for the transmission and rotor system.

Landing Gear Vertical Force Attenuation

Otpimum = 20 points

The landing gear will ideally exert an upward force of 10-15G through its maximum travel to the point at which the fuselage structure impacts the ground and begins to absorb energy. Various kinds of energy-absorbing methods can be utilized to achieve the desired results. For example: the Bell OH-4A Aircraft utilizes tapered wall lateral support tubes which absorb energy by bending; whereas, the presidential Sikorsky Aircraft utilizes a telescopic principle in which honeycomb material is crushed.

The amount of force required to deform the gear vertically until fuselage belly contact is made should be known in order to evaluate this factor. The standard aircraft oleo strut is a poor energy-absorbing mechanism because it cannot stroke rapidly enough in most severe accidents.

Landing Gear Location

Optimum = 5 points

Evaluate the damage which will be caused by this large mass as it is displaced during a crash. For example, if the gear is located directly under the cabin floor, the probability of its being driven upward into the occupiable area must be evaluated. No consideration need be given to the relationship of ignition sources to the landing gear since these items are evaluated under Postcrash Fire Potential.

EVALUATION

Ease and Reliability of Exit Operation

Optimum = 15 points

Evaluate from a standpoint of simplicity of operation. Include the regular entrance doors. Look for a "single motion" jettison feature on all doors and their capability of being opened from the outside. Check for possibility of jamming during crash due to fuselage distortion, etc. Check equal distribution of emergency exits throughout aircraft to ensure that all passengers move about the same distance from their seats to the exit.

Ratio of Usable Exits to Occupants

Optimum = 15 points

When computing a ratio, include cockpit exits that are available to those occupants; i.e., do not include cockpit exits in the ratio for cabin occupants. Assign a rating to this ratio for cabin occupants. Assign a rating to this ratio which reflects an evacuation time of 30 seconds for all occupants. Assume that one occupant requires approximately 1.5 seconds to egress an emergency exit and that 50 per cent of the exits may be blocked if the aircraft comes to rest on its side. Thus, on this basis one exit is required for each ten passengers. An additional exit is required if the capacity is not evenly divisible by 10 (e.g., 21 passengers would require three exits).

Identification of Exits

Optimum = 10 points

Emergency exits should be clearly marked and readily identifiable as such. The identifying letters should be a minimum of 3/4 inch high, and they must be lighted by the emergency lighting system. Operation instructions should be readily readable; should be a minimum of 1/3 inch in height; and colour should be offset, as red on white or vice versa. Do not use optimum unless a method is used whereby the passenger is instructed as to the exit he should use for his particular seating position. This may be accomplished by suitable markings on the wall or seat back ahead; this method is considered necessary to alleviate panic and confusion in case of an emergency. An aircraft with up to nine passengers would not need to abide by the requirements instructing the passengers to specific exits, since at least one entry door would be provided and its location and method of approach would be obvious.

Availability of Exits in Rolled Aircraft

Optimum = 10 points

Use the above ratio considering the aircraft rolled on either side, thereby blocking a certain number of exits. Take into account the size of the available exits (at least 22 inches square) and the height above the opposite wall. A fuselage width of 5 feet or more is considered too great for an occupant to climb in order to reach an exit.

Emergency Lighting

Optimum = 10 points

Check for system used: impact switch (G limit) or hand operated; a combination of the two is preferred. Check for independent power supply.

INJURIOUS ENVIRONMENT

Proximity of Cockpit Control Panels and Other Structure

Optimum = 10 points

Check if cockpit occupant is able to contact control panels when restrained with lap belt and shoulder straps. Check if shoulder straps allow lateral movement and what structure can be contacted in this manner. Evaluate this throughout the adjustment range of the seat.

Retention of Interior Equipment

Optimum = 10 points

Check the tiedown design strength of equipment such as fire extinguishing bottles, tool boxes, etc. and evaluate against an optimum of 25G.

Anti-Torque Pedal Area

Optimum = 5 points

Evaluate the possibility of trapping the feet between the rudder pedals and adjacent structure. Check if area may collapse onto the feet during crash. Rudder pedal should support both the ball of the foot and the heel. A simple bar-type pedal is unsatisfactory.

Absence of Injurious Objects in Cabin

Optimum = 5 points

Check for sharp corners, protrusions, etc., in the vicinity of the seated occupants.

CHAPTER XIV

SELF-PRESERVATION

Up to this point this book has been aimed at a number of levels. It should be apparent by this time that the helicopter pilot is a vulnerable human being who even at the best of times is marginally functioning in the aviation environment. He is being constantly exposed to considerable stresses which serve to erode and degrade his level of performance and diminish his well-being. The critical nature of helicopter flying and the stresses which it imposes on the man go a long way towards explaining the high incidence of accidents in helicopter operations.

Fig. 14-1 by G. Shorey

This Chapter then is aimed at the helicopter pilot himself, as well as the operator, and will provide some suggestions concerning possible ways of reducing the helicopter accident rate and preserving health and well-being in the pilot, thereby protecting these two valuable commodities, i.e., the pilot and the helicopter.

Crash Protection

It is obvious that helicopter accidents are going to continue to occur although at a hopefully lower rate than at the present time. It is satisfying to note that some companies are making great advances in terms of improving crashworthiness of helicopters, particularly in regard to energy absorption and crashworthly fuel systems. However, there are a number of things which the pilot may do himself to provide more protection, particularly in machines which have not been retrofitted with improved crashworthiness systems.

The two biggest killers in surviveable helicopter accidents, as pointed out in a previous Chapter, are head injury and fire. Therefore, it follows that use of shoulder harnesses to prevent flailing of the upper torso, and also, whenever possible, the use of helmets by helicopter pilots and passengers will serve to reduce the incidence of head injuries. There is some debate over whether helmets actually reduce the incidence of head injuries in helicopter crashes where harnesses are used, but it must be remembered that in helicopter accidents, penetration of the cockpit is one factor which is often present during the sequence of events. This may be by branches of trees or other foreign objects or penetration by a rotor or part of the helicopter.

Several good helmets are available on the market and if one examines what is being used by the US military and the Canadian military it is possible to discover types of helmets which provide a maximum of protection. The helmet should be relatively light weight and allow for some ventilation around the head. It should be light coloured in order to prevent absorption of heat and allow for ample head movement without any obstruction of peripheral vision. It should preferably be equipped with ear defenders for hearing conservation purposes and, if so, a headset and boom microphone can be installed on the helmet. It should have a minimum of projections to avoid snagging on structures when attempting to escape from a wreckage.

Many helicopter helmets are available which have built-in visors both clear and tinted. These provide some protection to the face and eyes in the event of the helicopter bubble being smashed by an object.

At least one Canadian company has purchased helmets for its pilots. In discussing the potential problems with the Flight Safety Officer, it was pointed out that passengers riding in the helicopter seemed to appreciate the fact that the pilot had a helmet. At least the pilot, according to the passengers, would not be knocked unconscious in the crash and would have the capability of rescuing them.

Helmets should be removed only <u>after</u> clearing the wreckage.

Energy Absorbing Seats

Energy-absorbing seats are not commonly available on helicopters manufactured before about 1975. At least one company, Bell, is installing energy-absorbing seats as standard equipment on all of its newer model helicopters. One type of seat involves a piston pressing a carbon fibre tube, whereas the other absorbs energy by bending wires as they are pulled through a roller system. Although energy-absorbing seats will be available on helicopters in the future, there still remains a large fleet of helicopters which are not fitted with these items. It is, therefore, suggested that energy-absorbing material be incorporated into the seat cushions. It is a relatively simple matter to remove the padding from the seat cushions and substitute the padding with an energy-absorbing type of foam. One such type is "Temper Foam", which is a polyurethane open cell material that combines flexibility, durability and light weight. It was originally developed for the NASA astronauts to ease discomfort during long flight and to cushion the "G" forces of lift-off and the impact of splashdown. This foam is available in different hardnesses. A combination of the softest and the next hardest foam was found to be suitable in aircraft seats and greatly improved the comfort as well as vibration damping characteristics. There may be some problem with cold weather in that the foam becomes a little more rigid and therefore loses some of its vibration-damping characteristics, but it is still drastically superior to the standard type of sponge rubber which is used in many modern day seats.

Shoulder Harnesses

Shoulder harnesses, preferably equipped with an inertia reel, should be installed on every aircraft if possible. Retrofit kits are available on the market for different models of helicopters. If these are installed inside the aircraft, a pilot should be sure to wear them as this can do a great deal in terms of preventing head injury and also, incidentally, relieving back pain.

Fire Protection

Since post-crash fire is a problem in many helicopters, especially older models, it follows that some sort of flame-resistant clothing should be worn. Standard synthetic clothes should be avoided, although there is at least one type of material "Nomex" on the market which is heat-resistant nylon. This material has been responsible for preventing burns and saving the lives of many pilots, especially in military operations. Standard synthetics tend to melt, causing severe burns.

If materials such as Nomex are not immediately available, fabric such as denim, woolen or cotton may be worn.

Gloves and boots accomplish a lot in terms of protection from burns. The trousers should be tucked into the boots in order to prevent the trouser legs from behaving like a chimney, which may serve to increase the severity of burns. Likewise, the shirt or jacket should either have a tight-fitting waist or should be tucked into the trousers. One-piece flying suits are preferable.

Sometimes it is possible to find, in war surplus stores, gloves which are manufactured out of a combination of Nomex and leather. These are superior to pure leather gloves because leather tends to contract when exposed to heat and therefore makes manipulation with the hands more difficult in a fire situation.

The pilot should maintain a high level of personal hygiene in case of injury or burns in order to prevent infection. Although there is some controversy about long hair and beards, I would recommend a short haircut and clean shaven face in order to prevent flaring in a fire situation. This may irk some helicopter pilots who seem to prefer a fuzzy visage and long hair.

Crash Position

Bell Helicopter Textron, in an Operations Safety Notice of June 27, 1980, suggested that when high impact landings or crashes are eminent, crew and passenger safety can be further enhanced by assuming the following body positions:

1. Seats with lap belts only

   Passengers should lean over until their chest rests on their thighs. Their arms should be clasped together under their thighs to hold this position. Front seat passengers must avoid interfering with the flight controls.

2. Seats with lap belt and shoulder harnesses

   Occupants should sit with their backs straight and against the seat back as much as possible. If a manual inertia reel lock is available and time and conditions permit, the inertia reel should be manually locked. Unless hands are required on the flight controls, their arms should be used to brace in the upright position.

Survival

Some knowledge of survival in various environments is essential. Excellent books and courses are available and pilots should avail themselves of these whenever possible. Although this is not the place for long discourse on survival, there are a few rules which I would like to mention.

1. Dress as if you had to stay out-of-doors all night.

2. Carry some survival items in your pockets - it is disheartening to watch a survival kit go up in flames. For survival food, the rules about simple carbohydrates can be broken - sugars provide energy while requiring little water. Some candies, such as barley sugar, matches, and a few small items can be wrapped in a garbage bag (itself a useful item) and stuffed into a pocket. Be sure to carry insect protection.

3. Keep these priorities in mind:

   (a) Protection - from the elements.

(b) Location - ensure that you can be spotted.

(c) Water - organize a water supply.

(d) Food.

HEALTH ASPECTS

Hearing Conservation

Because of the high sound pressure levels in and around helicopters, pilots and crew members as well as passengers should use some form of hearing conservation. Ear plugs do serve to reduce the sound pressure levels reaching the eardrum to some extent, but more effective are bun type ear defenders. For short-term exposures disposable ear plugs may be issued to the passengers and crew members, but for longer-term exposures proper ear defenders should be employed.

Pilots and crew members should have helmets with ear defenders installed or headsets with good sound attenuation properties. There are many acceptable brands on the market, but two such types are the David Clarke and Telex sets.

Vibration Damping

Proper vibration damping in helicopters is extremely important to reduce the pathology which can be caused by constant exposure to vibration. As discussed before, this includes back problems but it is possible that adverse effects could also occur, for example, in pregnant women if the resonant frequency of the uterus is reached.

Backache

In order to reduce the incidence of backache it is recommended that pilots maintain their ideal weight. They should also attempt to sit upright and avoid leaning to the left or twisting their spines to the left. In operations such as police work where binoculars or cameras may have to be held, it is recommended that some support be given to these and also some support be given to the back. As discussed in an earlier Chapter, lumbar supports have been found to be effective in reducing backache problems in pilots. It is recommended that pilots obtain one of the many readily available on the market and experiment with their use even before backache problems commence. Keeping one's shoulder harness done up also gives some support to the back and results in less fatigue.

Nutrition

Pilots should eat a well-balanced nutritious type of diet. Fatty foods and simple carbohydrates should be avoided. In order to maintain a reasonably constant blood sugar, it is recommended that small snacks be taken. These could consist of granola or fruit or some other substance which is low in fat and simple carbohydrates.

Breakfast is an extremely important meal of the day and should not be avoided. Likewise, other meals should be consumed on as regular a basis as possible and there should be an abundance of fresh vegetables and salads, as well as fresh fruits. Sugary desserts should be avoided as should greasy foods and gravies. It is known that diets which are high in vegetable and fibre are healthy in terms of preventing hypoglycemia, diabetes, coronary artery disease and hypertension.

Pilots should adopt some sort of a regular exercise program such as jogging, walking or swimming. This contributes to a sense of well-being and alertness as well as keeping the muscles in tone. Relaxation exercises have been found to be effective in treatment of backache in some individuals, according to the British Airways Study. Particular attention should be paid to nutrition when operating in cold climates and at high levels such as in mountain flying. When working in hot thermal environments, some experts recommend the use of salt supplements, but it is usually sufficient to add salt to regular food.

Alcohol

Excessive alcohol ingestion should be avoided at all costs. Alcohol not only results in hypoglycemia but also contributes to hypoxia through "poisoning" of the cells (histotoxic hypoxia). A person flying with a hangover state also experiences some problems with information processing as his nervous system becomes exceedingly sensitive and the ability to filter wanted from unwanted information is diminished. This may lead to coning of attention and tunnel vision, expecially in situations requiring a great deal of concentration of skill. In addition it is known that alcohol results in thinning of the fluid in the inner ear which decreases one's tolerance to disorientation particularly vestibular disorientation. Nystagmus (side to side flicking of the eyes) has been noted in many persons for 24 to 48 hours following ingestion of alcohol. A good rule to observe is 12 hours from bottle to throttle or 8 hours from cork to cockpit. However, if excessive alcohol has been imbibed, then this period should probably be lengthened. The pilot should be able to assess his own capabilities in this regard and if he feels unwell, he is probably unfit to fly. Also remember that a hangover state increases one's susceptibility to flicker and convulsions and decreases one's tolerance to G forces.

Smoking

Not only is smoking distracting to a pilot, but it also has other effects not only on him but the machine itself. For example, sensitive gyro instruments are unable to filter all of the tars and become inoperative after long periods of exposure to tobacco smoke. Smoking also results in a haze on the inside of the bubble which results in increased susceptibility to misting and formation of halos on the bubble. In pilot terms, smoking results in hypoxia on a short-term basis, but also the risks to health are increased manyfold.

Not only can smoking hinder performance in the cockpit, but it may cause chronic medical conditions which can lead to loss of licence. A 30-year-old who uses two packs of cigarettes a day will statistically live 8.5 years less than the comparable non-smoker, and the conditions causing this may lead to loss of licence at a relative young age. Cigarette smoking hinders the ability of the respiratory passages to

reject mucus and debris resulting in a predispostion to tracheitis, bronchitis and other infections. Chronic diseases such as emphysema causing shortness of breath in early stages and later causing the individual to become a respiratory cripple are more common in smokers - cigarette smoking accounts for 75% of emphysema cases. It is common knowledge that the risk of lung cancer is markedly greater in cigarette smokers, but they also have a higher incidence of cancer of the larynx, pharynx, mouth, esophagus, pancreas and urinary bladder.

Cigarette smoking is recognized as a major risk factor in production of coronary artery disease. The statistical risk of experiencing a heart attack is increased six times in smokers over non-smokers. In addition, smokers may also develop eye diseases such as inflammation of the optic nerve resulting in blind spots, and the combustion products of tobacco have a direct irritating effect on the corneal and conjunctival tissues of the pilot and passengers.

Aside from these specific conditions, cigarettes aggravate tiredness, contribute to headaches, chronic coughing, nervousness, shortness of breath and poor general health, all of which are contributors to the cause factor often evident in aircraft accidents, namely "failure to exercise good judgment".

Self-Medication

Self-medication is not recommended for two main reasons. First the condition which causes the individual to use a medication may interfere with mental function. This may be simply distraction due to pain or there may be a direct impairment of brain function. Secondly, almost all medications have side effects. It is rare for a medication to affect only the condition for which it is being taken without affecting other systems or resulting in other symptoms.

It must be borne in mind that a symptom which may be mild in a doctor's office or in an easy chair at home may become extremely distressing during a critical manoeuvre in the aviation environment and could lead to an accident.

If a helicopter pilot is seeking the advice of a doctor, the doctor should be made aware of the pilot's occupation as this may affect the type of medication or advice concerning subsequent ability to fly.

Vision

A pilot's eyes are his most precious asset and care must be taken to preserve good vision. This should include protection of the eyes in windy or dirty environments or when working around toxic chemicals or in machine shops. Pilots should not be reluctant to seek correction when presbyopia develops. If bifocals are required then a good type as described in Chapter VI should be purchased so that there is minimum interference with the visual fields. If the machine which is being operated is equipped with an overhead panel, it is possible to obtain visual correction at the top part of the lens as well.

Glare can be annoying and may cause problems in flying. The main types of glare are veiling glare due to dust or scratches on the bubble, glare due to interocular scatter,

and scotomatic glare where the retina becomes bleached as a result of exposure to dazzling light.

Sunglasses can do much in reducing eye fatigue as a result of glare. The glasses should be reasonably light, have a relatively small frame and yet large enough to cover most of the fields of vision. Although neutral grey glasses are recommended in order to prevent colour distortion, most green tinted glasses are acceptable. I have tested the "ambermatic" type of photosensitive lens and have found that they change rapidly enough for helicopter flying. In addition, when individuals were tested with the isochromatic plates, there were fewer errors with the "ambermatic" lens than there were with green tinted lenses, particularly in the blue area of the spectrum.

Some helicopter bubbles and windscreens show interference rings (Newton's Rings) when polarizing lenses are used. Polarizing lenses are effective in reducing glare, but if these rings show up in your particular machine then they should not be used.

For night flying, adequate cockpit lighting is required. The lighting level should be adjusted so that it is comfortable and undue strain is not placed on the eyes. Red light results in some degree of myopia in older pilots - it is often the harbinger of presbyopia. Cool white lighting which is actually in the red end of the spectrum is commonly used in modern aircraft.

SAFETY ASPECTS

Fatigue

As the study by Billings indicates, skill fatigue develops fairly rapidly in helicopter flying, as low as two hours even in experienced helicopter pilots. Therefore, vigilance should be increased throughout the day keeping this in mind. Important in prevention of fatigue are proper rest and diet. As indicated, smoking contributes to fatigue as do other stresses such as noise, vibration, flicker and thermal stresses.

Mission Accomplishment

Many accidents have been caused by a self-imposed urgency of mission accomplishment. A realistic evaluation of each situation should be made, especially before charging off into deteriorating weather or operating under dangerous circumstances.

A recent accident (1981) illustrates this aspect: A check pilot for a company was checking out a new pilot when they flew into a lake. The weather was foggy - not even birds were flying. The check pilot, who was killed, was to leave for a holiday in the south the next morning. This example could also be used in the following condition:

"Get Home Itis"

This can be a particularly devastating phenomenon, especially after periods of isolation or on Friday afternoons where a return to more comfortable surroundings

may result in motivating factors which override safety considerations. Again in the face of deteriorating weather or other dangerous operating situations, realistic self-appraisal must be made.

"Got-It-Made" Syndrome

This occurs when pilots have been through difficult times or weather and have returned to more familiar surroundings. Sometimes because of the high period of stress, there is a rebound to a lower level of vigilance which may result in carelessness or errors, especially errors of omission. This may be noted in training situations where following graduation of students, instructors may commit errors by doing things or failing to do things that would be unthinkable in a training situation or for that matter in any normal operating situation.

Another situation where the got-it-made syndrome occurs is after flying through bad weather and upon breaking out into familiar surroundings, the pilot relaxes, in fact over-relaxes, and allows himself to blunder and commit a ridiculous error such as taxiing into another aircraft. Pilots should keep in mind that they are still vulnerable to having an accident until they are sitting at home in their rocking chairs.

Deteriorating Weather

Helicopter pilots are prone to flying into deteriorating weather as they are capable of operating close to the ground at low speeds. As discussed previously, however, this may result in accidents.

Another situation which causes accidents is whiteout. Pilots should have in mind some sort of drill to follow should they encounter whiteout conditions, and should have some basic training on instruments to allow them to return to better visibility conditions. Sadly enough, many of these accidents result from controlled impact with the ground.

Chemical Handling and Exposure

Helicopters are becoming increasingly involved in agricultural operations because of their ability to operate close to the ground at relatively low speeds and because the turbulence which is caused by the rotors can result in a more even distribution of chemicals to the underside of leaves, etc. Pilots must be aware that often they are applying extremely toxic substances, particularly when using organophosphates or carbamates which have the same effects as nerve gases. Some chemicals are so toxic that a single drop in the eye can result in disability or death.

When handling toxic chemicals pilots should make themselves familiar with the manufacturer's instructions and should follow necessary precautions to the letter. When operating in various areas, the local hospital should be made aware of the chemicals which are being used and the antidotal instructions should be provided to the hospital.

Pilots should not be involved in mixing or loading chemicals, and when these are being mixed or loaded, the pilot should remain upwind of the area. Pilots and ground crew

alike should not smoke or eat around chemical areas as this might result in oral absorption of these chemicals. Personal cleanliness and hygiene is extremely important. Clothing should be washed daily if possible, and after a day's operation a pilot should shower himself completely with soapy water and rinse well. The machine should be kept as clean as possible and it must be remembered that some chemical is bound to enter the cockpit of the aircraft through recirculation. Therefore, the pilot should wear adequate protective equipment and the instructions provided with the equipment be followed. For example, carbon canisters in some masks require replacing every eight hours or they are ineffective. The safety equipment should be selected for protection to the eyes and, of course, respiratory functions. Protective clothing such as gloves and coveralls should be worn and, as mentioned previously, cleaned daily.

The pilot, if feeling unwell, should seek medical attention. Self-medication with atropine pills results in decreased ability to sweat and also interferes with vision. Cases of atropinism have been reported in pilots who over-medicated themselves.

Low level Turns

Low-level turns in windy conditions may result in visual illusions causing cross control. Inexperienced pilots tend to try to turn around some fixed object on the ground. When turning from downwind, this may result in too tight a turn and cross controlling. Turning from upwind may result in a loss of airspeed as the pilot may inadvertently attempt to maintain a constant groundspeed. Pilots should therefore pay attention to their air speed and needle and ball to ensure coordinated turns.

Wire Strikes

Wire strikes are a major factor in many helicopter accidents. Pilots should be aware of where to expect wires and avoidance techniques. If possible wire cutting devices should be installed on the helicopter if it is to be operated at low levels and high speed.

Before agricultural operations or before using a new landing area, the field should be surveyed, preferably from the ground, prior to commencement of the operation.

Passenger Briefing

Passengers should be briefed before flight concerning the danger associated with the tail rotor and main rotor and instructed on how to approach the helicopter. It should be kept in mind that if they are accustomed to working around fixed-wing aircraft, they are briefed to approach from behind which is dangerous with helicopters. Passenger boarding areas should be kept secure if possible and there should not be unnecessary traffic around the machines. Posters and pamphlets are available which demonstrate safe ways to approach a helicopter as well as unsafe practices such as approaching a running machine from uphill.

Careful positioning of the machine may help to avoid obliging the passengers to approach the helicopter from an unsafe direction.

OPERATORS

Helicopter operators can do much to improve the lot of the helicopter pilot and also create a safer operating organization. Safety regulations should be enforced by supervisory personnel, and the pilot should be encouraged to maintain their health.

Crew rooms and proper rest facilities should be provided. The crew room should be handy to the flight line, clean, bright, and well furnished. Likewise meal and snack facilities should be adequate, and careful thought should go into menu preparation. Pilots should be given the opportunity to choose fresh vegetables and salads as well as fruit at mealtimes and for snacks.

When purchasing machines, safety equipment which is optional such as shoulder harnesses, high seat backs and crashworthy fuel systems should be purchased. In the case of retrofits, if crashworthy fuel systems are available for the machine they should be purchased and, in addition, energy absorbing cushions and shoulder harnesses, preferably with inertia reels, should be installed.

Passengers and new crewmen should be briefed concerning operating around helicopters. Safety posters should be displayed in prominent locations and security on the flight line should be maintained. Maintenance facilities should be clean and well lit. The machine should be clean and well maintained and rotors should be kept balanced in order to cut down on vibration.

CHAPTER XV

THE FUTURE

There remains some uncertainty as to what the future will hold in terms of helicopter development. Some would believe that the helicopter is an interim step between fast fixed-wing aircraft and rapid aircraft which would have a capability of vertical take off and landing and hovering. This type of aircraft has progressed long past the drawing board stage and there are several prototypes now in the air. One type, designed by Bell, has a tilt wing with a 25-foot rotor on each wing tip. The aircraft can take off vertically and hover and transition to a fixed-wing mode by tilting the wings and rotors forward. At this time, in the fixed-wing mode, the aircraft has far exceeded the maximum cruising possibilities available in helicopters.

In military operations a vertical take-off and landing aircraft, the Harrier, designed in Britain, is already in service. It is capable of lifting off vertically and manoevring in hovering flight. However, the fuel efficiency is relatively low in this model.

For many types of applications, however, it would appear that the helicopter is here to stay. For short duration flights where hovering is required, for example, in hydro operations where poles and towers are lowered into place, and in slinging operations, the helicopter has obvious applications. Therefore, it is inevitable that improvements will be made in all aspects of design as technology and the state-of-the-art advances. Dangers are inherent, however, and considerations of the human flying the machine must be allowed to a greater extent than has been done in the past. As technological advances improve structural and component reliability, an upswing in the proportion of human factors causing accidents will occur.

Before the aviation community allows this to happen, close attention must be paid to the human factors of helicopter operations. Hopefully, the tendency to apply fixed-wing principles to rotory-wing flight will cease as designers, operators and pilots gain more insight into the relationship between man and helicopter, and give due consideration to the fact that helicopter flying is a new and different ballgame.

We have made many mistakes in the past and must learn from this experience in order to prevent further errors in the future. This principle demands good communication and cooperation amongst many disciplines, and personal and economic considerations must be set aside to some extent. After all, the final goal is safe and expeditious transportation which means flight safety and, in the long run, safety is the most economical approach, although greater demands are incurred initially. Surely the economy of operation would be improved with a machine which is easier and safer to operate and can be flown for longer periods without undue stress being placed upon the pilot. It is obvious that a good selling program is necessary before present limitations can be overcome.

Education is probably the major key which can unlock the present hangups, as only an informed public can effect improvements in helicopter design and operation. Pilots must be informed of the various stresses, etc., which can compromise their ability and judgment in order that they may better assess their own limitations.

Likewise, those who employ helicopters in operations must be informed of these problems so that they may also understand the limitations of man and machine and will not have the tendency to make undue demands upon them. In addition, aspiring helicopter pilots should consider the operational environments and the hardships which they may be called upon to endure in the usually isolated settings, and then evaluate their own motivations so a reasonable judgment can be made before training is initiated. This would diminish the dissolutionment which is so often seen in individuals whose primary consideration is to fly helicopters and, when the initial thrill wears off, become frustrated by the task at hand.

As far as design is concerned, it has been shown that a mistake has been made in trying to apply known and accepted fixed-wing principles to a new concept. Human beings are much like electrons in trying to take the path of least resistance and therefore, understandably, have committed some errors. The author has shown that, for example, a fixed-wing artificial horizon is not appropriate in helicopters and that some of the usual fixed-wing operating procedures don't apply. Perhaps designers, now that they have a wealth of experience and information, should start from square one and totally redesign the man-machine interface, considering even such basic items as controls and displays. Because the stick and pedal arrangement works well in the standard aircraft, it does not necessarily follow that a simpler and more efficient control system could not be incorporated in helicopters. A single multi-axis control may well be better suited.

At the same time, improved safety would result from standardization of cockpit layouts and improved designs of instruments to reduce the incidence of design-induced pilot error. Known factors in human information processing must be considered. The incorporation of noise attenuating padding and vibration damping along with anthropometric adjustable seats would do much to improve pilot comfort and efficiency. Improved crash survivability would not only result in safer operations, but would also do much for pilot morale.

All of the above changes in design would require considerable cooperation between various manufacturers, which would be difficult but not impossible to achieve in the competitive setting. However, in this natural resource sensitive era the rewards of cheaper exploration and transportation would benefit the helicopter industry in the long run and benefits to the rest of society are obvious.

Finally, even if improvements are incorporated into helicopters of the future, a large inventory of older machines will exist for some time. Some improvements in safety can be achieved by modification and retrofit, particularly for occupant protection. Existing restraints could be used in place of foam rubber seat cushions, etc. Personal safety equipment such as flame resistant flying suits, (e.g. Nomex) and crash helmets, if used, would undoubtedly do much to improve survivability statistics.

Much of this manuscript has been devoted to deliniating some of the shortcomings of helicopters and suggestions have been made as to how some improvements can be made. The reader, if he has not succumbed to boredom and given up long before this, will most likely have a one-sided view of helicopters and helicopter flying.

To be sure, there is another side. The helicopter is an exciting machine to fly. No other type of aircraft provides a pilot with the equivalent amount of challenge and freedom as does a helicopter. To be able to manoeuvre in any dimension and land on almost any spot, to slow down or speed up as one desires, or to see the broad expanse of earth from inside the cockpit are only a few of the attractions which make flying helicopters so enjoyable. There is a sense of achievement of true flight which has attracted the imaginations of men since time began. There are few thrills so great as the exaltation and freedom of flight on whirling, flexing wings.

Photo 15-1

REFERENCES

1. Benson, A.J.: Spatial Disorientation and the "Break-off" Phenomena Aerospace Medicine, August 1973.

2. Billings, et al: Physiological Cost of Piloting Rotary Wing Aircraft, Aerospace Medicine, March 1970, Vol. 41 No. 3.

3. Billings, et al: Stress and Strain in Student Helicopter Pilots.

4. Billings, et al: Studies of Pilot Performance. Evaluation of Performance During Low Altitude Flight in Helicopters Aerospace Medicine, January 1968, Vol. 39 No. 1.

5. Billings, Chas E. et al: Studies of Pilot Performance; 111. Validation of Objective Performance Manoeuvers for Rotary-Wing aircraft. Aerospace Medicine September 1973.

6. Brugginia: Emergency Landing and Ditching Techniques in Helicopters. AGARD Conference Proceedings No. 24.

7 Bynum, James A. et al: Development of a Paint Scheme for Increasing Helicopter Conspicuity. USAARU Report No. 68 - 1.

8. Bynum, James A. et al: Painted Helicopter Main Rotor Blades and Flicker-Induced Vertigo. USAARU Report No. 68 - 11.

9. Camp: Noise Spectra of the U.S. Army OH-58A Helicopter. USAARL Letter Report.

10. Crosley, John K. et al: Improving U.S. Army Aircraft Propeller and Tail Rotor Blade Conspicuity with Paint. USAARL Report No. 72-15.

11. Eastwood: Disorientation in Helicopter Pilots. Aerospace Medicine, March 1970.

12. Eley, Wg. Cdr. D.: Problems of Training Army Helicopter Pilots. AGARD Conference Proceedings Series No. 24.

13. Forbes, David T.: What is Flicker Vertigo? U.S. Army Aviation Digest December 1971.

14. Gessow, Alfred/Ungar, Garry C. Myers, Jr. Aerodynamics of the Helicopter. 1967.

15. Grether, et al: Effects of Heat, Noise and Vibration Stress. Aerospace Medicine, October 1971, Vol. 42 No. 10.

16. Haley: Helicopter Structural Design for Impact Survival. American Helicopter Society.

17. Haley, Joseph L.: Surviving the Survivable. U.S. Army Aviation Digest December 1971.

18. Littel: Heat Stress on OH58A Helicopter Crews. USAARL Letter Report V53 December 1969.

19. Mackiae, Surg. Cdr.: Operation of Helicopters - Some Visual Problems. AGARD Conference Proceedings Series No. 24.

20. Mattox: Crash Injuries in U.S. Army Helicopter Accidents. AGARD.

21. Melton, et al: Exposure of Men to Intermittent Photic Stimulation. Under Simulated IFR Conditions. FAA Project No. AM 64-3, phys. 1 Report No. AM 66-39.

22. Obden, et al: Disorientation in Army Helicopter Pilots. U.S. Army Board for Aviation Accident Research, Report No. 2-64.

23. Schane, W.P.: Continuous EKG Recording of Helicopter Instructor Pilots. An Interim Evaluation. U.S. Army Aeromedical Research Laboratory Report No. 69-5.

24. Schane, W.P.: Effects of Downwash Upon Man. USAARU Report No. 68-3.

25. Seris, H. et al: Vibration sur le hélicoptère. AGARD Conference Proceedings No. 24.

26. Simson, Lawrence R.: "Chin - Sternum - Heart Syndrome" Parachuting Mishaps. Aerospace Medicine, November 1971 Vol. 42 No. 11.

27. Stern, et al: Analysis of Visual Search Activity in Helicopter Pilots. Aerospace Medicine, March 1970 Vo. 41 No. 3.

28. U.S. AAMRDL Technical Report 71-22: Crash Survival Design Guide.

29. U.S. Navy Flight Surgeon's Manual.

30. Borchsrevink, Hans M.: Second Language Speech Comprehension in Noise - A Hazard to Aviation Safety.

31. Vinson, D.B.: Mental Time Sharing in the Human Operator.

32. Mohler, Stanley R.: Mental Functionin Safe Pilot Performance. Flight Safety Foundation Inc. Human Factors Bulletin - Jan/Feb. 1979.

33. Nicholson, A.N. et al: Influence of Workload on the Neurological State of a Pilot During the Approach and Landing. Aerospace Medicine, Feb. 1973.

34. Grey, Walter.

35. Miller, J.G. (1960) Input Overload and Psychopathology. American Journal of Psychiatry 116, 695-704.

36. Elliot, R.J.: Weather Accidents: The Odds. Helicopters in Canada, Fall 1980.

37. Clinical Neurology - 2nd Edition - Frank A. Elliott, M.D., FRCP, Aerospace Medicine 44(8): 953-955, 1973.

38. Russel, B. Rayman: Sudden Incapacitation in Flight. Aerospace Medicine 44(8): 953-955, 1973.

39. Harper, C.R.; Kidera, G.J.: Hypoglycemia in Airline Pilots. Aerospace Medicine, July 1973.

40. Taylor, Ellis R.: The Incidence of Hypoglycemia in Flight. Air University, School of Aviation Medicine, Randolph AFB Texas, Feb. 1959.

41. Hutchison, R.C.: Effect of Gastric Contents on Mental Concentration and Production Rate. Journal of Applied Physiology, Vol. 7 No. 2, Sept. 1954.

42. Ou, L.C.: Hepatic and Renal Gluconeogenesis in Rats Acclimatised to High Altitude. Journal of Applied Physiology, Vol. 36(3), March 1974.

43. Goede, R.: Backache in Helicopter Pilots. Flight Comment, 4th Edicion, 1977.

44. Whiteside. Aviation Medicine, Vol. 2. Tri-Med. London, page 305.

45. McCormick, Ernest J: Human Engineering. McGraw-Hill Book Company, 1957.

46. Teobaldo, Llosa-Rojas: Flying Decompensation Syndrome and Fear of Flying. Aerospace Medicine, Sept. 1974.

APPENDIX A

CHECKLIST I

HUMAN FACTORS INVESTIGATION

	FACTOR	WHERE AVAILABLE
I	**Information Processing**	
	A. Information Overload (regression, cueing, withdrawal)	Tower tapes, analysis of flight profile, timing, wreckage, pilot manuals.
II	**Motivation**	
	Esp. Hot Pilot & Fear of Flying	No. of flying hours, reaction of peers, other interests, school records, flying and driving habits, offences, reading interests, e.g., accidents treatment by physician, reactions to accidents, satisfaction with flying aspiration vs. achievement flight planning, weather briefing.
	Fear of Flying Risk-taking tendency	
III	**Vision**	
	A. Visual acuity	Medical, glasses, lens on person. Driving history - work history.
	Lighting	e.g., in shop
	B. Illusions	Weather conditions, precip. Glassy water.
	C. Runway Illusions	Runway & undershoot profile. Tire mark concentration.
IV	**Vestibular Disorientation**	
	A. "Vertigo"	Weather, experience, training, instruments, flight path, impact, position of radios, etc.
	B. Somatogravic	Light, lighting (natural & artificial) instrument types (e.g., VSI vs. IVSI) flight profile (e.g., dark night takeoff illusion).

C. Low Level Illusions		Wind direction, speed, flight profile, lighting, location & size of wires, temperature.
V **Combined Factors**		
A. External Stresses		
	1. Hypoxia	Flight profile, health (MER) smoking, 02 equipment.
	2. Dysbarisms	History; cold or illness.
	3. Thermal	Outside & cockpit environment, sweat in garments.
	4. Flicker	Direction of sun and shadow makers.
	5. Hyperventilation	Flight profile, symptoms, CVR, tower recordings.
	6. Vibration, Turbulence	Weather, machine characteristics.
	7. Toxic	CO level, chemical exposure, protective equipment.
	8. Circadian Rhythm	Shifts, time zone changes, long distance flights.
B. Internal Stress		
	1. Conflicts	Family attitude, financial, arguments.
	2. Hypoglycemia	Meals, dietary habits, stomach contents.
	3. Fatigue	Hours flown, on duty, rest pattern. History of previous 48 hours - concurrent illness.
	4. Hangover	Activities, drinking patterns.
	5. Illness	History; family or physician, medications, autopsy witnesses.
	6. Get home "itis"	Business, social pressures, peers, flying practices.
	7. Got-it-made "itis"	Flight history & difficulties - previous flight conditioning - tower tapes.

VI	**Human Engineering**	
	A. Workspace Design	Operators' manuals, design plans, brochures, other AC/
	1. Anthropometry	Autopsy, measurement, clothing.
	B. Displays	Wreckage, other AC/, brochures, operators' manuals.
	C. Warnings	Voice records, incident reports - reliability of warnings (servicing).
	D. Controls	Wreckage, other AC/, brochures, manuals.
VII	**Incapacitation**	
	A. Medical	History of previous illness.
		Evidence of previous incapacitation, i.e., road, domestic, recreational injury.
		Evidence of treatment & family physician, drugs, self-medication (family, peers).
		Performance prior to accident - sequence.
		History of flight, including meals.
		Actions compatible with diminished consciousness, i.e., lowering flaps, u/c etc. (incl. FDR).
		Accident sequence flight profile analysis for:
		evidence of change of sequence evidence of control input (or lack) evidence of attempted control take-over by second party evidence of prodromal signs
		Autopsy for hand/foot injury pattern:
		evidence of disease evidence of impact dynamics tissue, hair matching.

		Biochemistry for: toxic substances and evidence of adrenergic reaction.
		Tower tapes/CVR for evidence of stress.
B.	Psychological	Psychological history for evidence promoting preoccupation or mood changes.
		Evidence of pre- or in-flight aggravation or annoyance - pre-flight history.
		Evidence of personality clash - history CVR tower tapes - witnesses.
		Evidence of information presentation ambiguity compatible with mental state.
C.	Toxic	Exposure to chemicals, tissue analysis - analysis of flight performance.
		History from peers and other witnesses.

APPENDIX B

CHECKLIST II

HUMAN FACTORS INVESTIGATION

	INFORMATION SOURCE	REASON FOR EXAMINATION
I	**5802-File - Pilot's File**	
	A. MER (Medical Examination Report)	Age, occupation, flying time, medical history, measurements (height and weight), eye colour and identification marks.
		Physical defects, visual or hearing problems, colour vision defects, name of medical examiner.
	B. Flight Test Reports	Flying experience, training, problems, weaknesses, habits, attitude, endorsements.
	C. Accident Records	Accident repeaters, problems.
		Attitude to authority, regulations.
II	**Manuals & Brochures**	Instrument types and location (conducive to illusions), radio and other control placement (vertigo inducing) colour of instruments, eye datum, anthropometry.
III	**Wreckage**	Control position (e.g., regression), glasses or contact lens, drugs, condition of windscreen, severity and direction of impact (e.g., vertigo), instruments available and settings, use of and adequacy of safety equipment, types of displays and controls, presence of toxic chemicals, leakage of CO, suicide notes.
IV	**Flight Profile**	
	A. History of Flight (including Flight Planning and Weather Briefing)	Timing, i.e., time, activity-position plot unusual occurrences or departures from normal operating procedures, professionalism, over or under confidence (e.g.,

		fuel load, pressing weather). Enroute weather (e.g., turbulence, IFR), time zone changes, information workload.
	B. Final Crash Profile	Disorientation, incapacitation, suicide, direction relative to sun, wind hazards.
	C. Tower Tapes	Timing, voice changes (e.g., hypoxia, drugs or alcohol, incapacitation, disease, panic), information overload, interrupted checks.
	D. Cockpit Voice Recorder	Timing, voice changes, other clues.
V	**Airport/Landing Field**	
	A. Funway Profile	Sloping runway illusions.
	B. Over/Undershoot Profile	Lighting, obstruction working.
	C. Tire Mark Concentration	
	D. Runway Width	Runway illusions (compare - home Airport)
	E. Obscuring Phenomena	Whiteout, snow dust.
	F. Local Lighting	
VI	**History - 48 hours (minimum)**	
	Available from family, peers.	Fatigue, hypoglycemia. Illness, self-medication, alcohol use, exposure to toxic hazards.
VII	**Witnesses**	
	A. Observers	- final flight path (incapacitation). - local weather conditions. - survival. - exposure to toxic chemicals.
	B. Family	- interests, motivation, experiences, conflicts (attitude toward flying of family), school attainment and driving record, aspirations, reactions to accidents. - health, family physician, medication, e.g., chest pain, shortness of breath.

		- personal habits; smoking, driving history, domestic/recreational accidents, dietary, drinking, reading interests.
		- use of glasses, sunglasses.
		- history of 48 hours, meals, fatigue.
		- social or business pressures.
C.	Peers	- attitude towards company.
		- assessment of ability, habits, interests, problems with aircraft.
		- behaviour, health, mood, social or business pressure.
		- history of 48 hours.
D.	Instructors	- ability, attitude, motivation, unusual occurences, anxiety, level of training.
		- machine problems.
		- business or social pressures (e.g., missing lessons, family attitude).
		- habits, drinking patterns.
E.	CAME and/or Family Physician	- medical history, illnesses, medication, social problems, referrals to other specialists.
F.	Logbook	- experience, neatness, interests.
G.	Company Executives Check Pilots, Linemen.	- company problems, pressures.
		- assessment of pilot's ability, motivation, e.g., tardiness, absenteeism.
		- maintenance problems, motivation of employees (absenteeism, turnover).
		- safety attitudes - bulletins, notices, newsletters, library.

VIII **Climatic**

Forecast, Aftercast, Local Conditions

A.	Weather	IFR, turbulence.
B.	Temperature	Heat or cold stress.
C.	A/C Conditioning	Heat or cold stress, toxic.

D.	Wind	Low level illusions, crosswind, distraction, turbulence.
E.	Cloud Cover, Obscuring Phenomena	- Disorientation, illusions.
F.	Sun, Brightness, Position	Glare, distraction, thermal stress due to greenhouse effect.

IX **Autopsy**

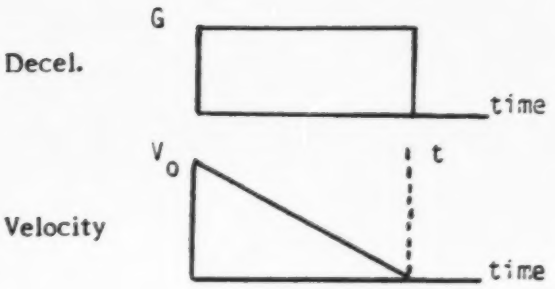
A.	Clothing	- marks, sweat, chemicals. - contents of pockets. - size (anthropometry).
B.	Gross Autopsy	- identification. - antecedent disease, previous injuries. - who was at controls. - sequence of events. - crashworthiness.
C.	Biochemical	- stomach chemicals. - alcohol, carbon monoxide, toxic chemicals, lactate profile (stress).
		- maintenance shops - lighting, tools, environment.

APPENDIX C

DECELERATION EQUATIONS

FOR THE CASE $V_f = 0$

1. RECTANGULAR PULSE



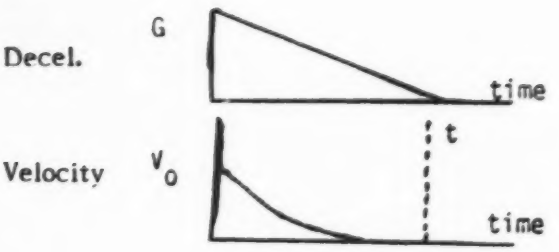
Pulse Duration: $t = \frac{V_o}{32.2G}$

Deceleration Level: $G = \frac{V_o^2}{64.4S}$

Stopping Distance: $S = \frac{V_o^2}{64.4G}$

Or: $S = \frac{32.2Gt^2}{2}$

II. TRIANGULAR PULSE NO. 1



Pulse Duration: $t = \frac{2V_o}{32.2G}$

Deceleration Level: $G = \frac{2V_o^2}{96.6S}$

Stopping Distance: $S = \frac{2V_o^2}{96.6G}$

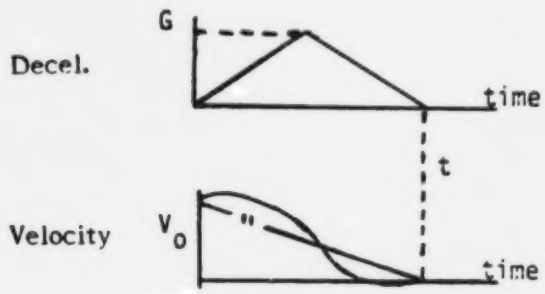
Or: $S = \frac{32.2Gt^2}{6}$

APPENDIX C

DECELERATION EQUATIONS

FOR THE CASE $V_{final} = 0$

III. TRIANGULAR PULSE NO. 2



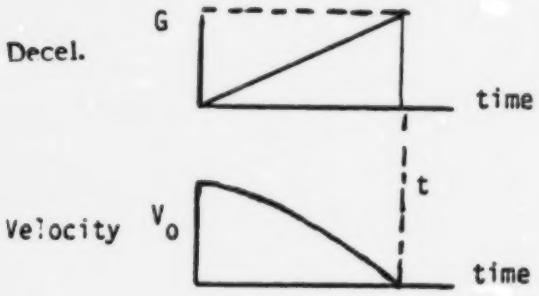
Pulse Duration: $t = \frac{2V_o}{32.2G}$

Deceleration Level: $G = \frac{V_o^2}{32.2S}$

Stopping Distance: $S = \frac{V_o^2}{32.2G}$

Or: $S = \frac{32.2Gt^2}{4}$

IV. TRIANGULAR PULSE NO. 3



Pulse Duration: $t = \frac{2V_o}{32.2G}$

Deceleration Level: $G = \frac{4V_o^2}{96.6S}$

Stopping Distance: $S = \frac{4V_o^2}{96.6G}$

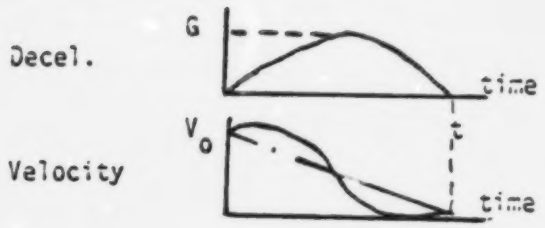
Or: $S = \frac{32.2Gt^2}{3}$

APPENDIX C

DECELERATION EQUATIONS

FOR THE CASE $V_f = 0$

V. HALF SINE PULSE



Pulse Duration: $t = \frac{1.57V_o}{32.2G}$

Deceleration Level: $G = \frac{0.7854V_o^2}{32.2S}$

Stopping Distance: $S = \frac{0.7854V_o^2}{32.2G}$

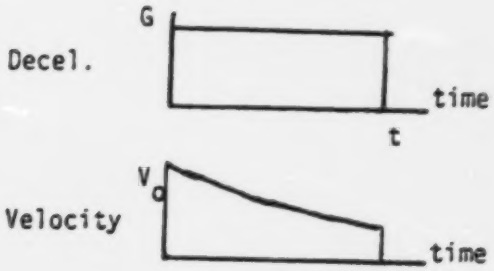
Or: $S = \frac{32.2Gt^2}{3.14}$

APPENDIX D

DECELERATION EQUATIONS

FOR THE CASE $V_f \neq 0$

1. RECTANGULAR PULSE



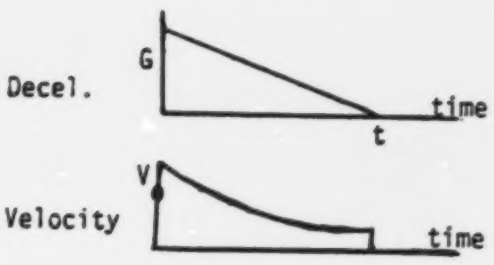
Pulse Duration: $t = \frac{V_o - V_f}{32.2G}$

Deceleration Level: $G = \frac{V_o^2 - V_f^2}{64.4S}$

Stopping Distance: $S = \frac{V_o^2 - V_f^2}{64.4G}$

Or: $S = V_o t - \frac{32.2Gt^2}{2}$

II. TRIANGULAR PULSE NO. 1



Pulse Duration: $t = \frac{2(V_o - V_f)}{32.2G}$

Deceleration Level: $G = \frac{2V_o^2 + 2V_oV_f - 4V_f^2}{96.6S}$

Stopping Distance: $S = \frac{2V_o^2 + 2V_oV_f - 4V_f^2}{96.6G}$

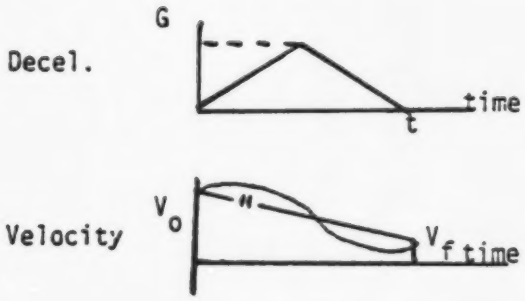
Or: $S = V_o t - \frac{32.2Gt^2}{3}$

APPENDIX D

DECELERATION EQUATIONS

FOR THE CASE $V_f \neq 0$

III. TRIANGULAR PULSE NO. 2



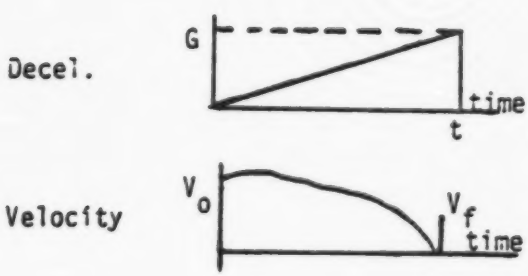
Pulse Duration: $t = \frac{2(V_o - V_f)}{32.2G}$

Deceleration Level: $G = \frac{V_o^2 - V_f^2}{32.2S}$

Stopping Distance: $S = \frac{V_o^2 - V_f^2}{32.2G}$

Or: $S = V_o t - \frac{32.2Gt^2}{4}$

IV. TRIANGULAR PULSE NO. 3



Pulse Duration: $t = \frac{2(V_o - V_f)}{32.2G}$

Deceleration Level: $G = \frac{4V_o^2 - 2V_oV_f - 2V_f^2}{96.6S}$

Stopping Distance: $S = \frac{4V_o^2 - 2V_oV_f - 2V_f^2}{96.6G}$

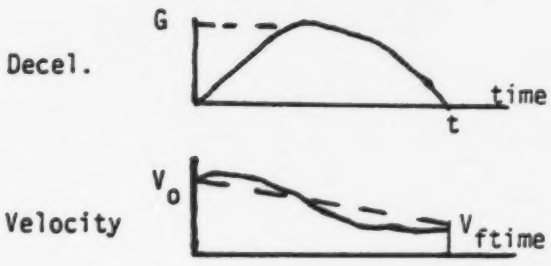
Or: $S = V_o t - \frac{32.2Gt^2}{6}$

APPENDIX D

DECELERATION EQUATIONS

FOR THE CASE $V_f \neq 0$

V. HALF SINE PULSE



Pulse Duration: $$t = \frac{1.57\ (V_o - V_f)}{32.2G}$$

Deceleration Level: $$G = \frac{0.7854\ (V_o^2 - V_f^2)}{32.2S}$$

Distance: $$S = \frac{0.7854\ (V_o^2 - V_f^2)}{32.2G}$$

Or: $$S = V_o t - \frac{32.2Gt^2}{3.14}$$

APPENDIX E

SINE = $\frac{\text{OPPOSITE}}{\text{HYPOTENEUSE}}$ COSINE = $\frac{\text{ADJACENT}}{\text{HYPOTENEUSE}}$ TANGENT = $\frac{\text{OPPOSITE}}{\text{ADJACENT}}$

Angle	Sine	Cosine	Tangent	Angle	Sine	Cosine	Tangent
0	0.000	1.000	0.000	45	0.707	.707	1.000
1	.018	1.000	.018	46	.719	.695	1.036
2	.035	0.999	.035	47	.731	.682	1.072
3	.052	.999	.052	48	.743	.669	1.111
4	.070	.998	.070	49	.755	.656	1.150
5	.087	.996	.088	50	.766	.643	1.192
6	.105	.995	.105	51	.777	.629	1.235
7	.122	.993	.123	52	.788	.616	1.280
8	.139	.990	.141	53	.799	.602	1.327
9	.156	.988	.159	54	.809	.588	1.376
10	.174	.985	.176	55	.819	.574	1.428
11	.191	.982	.194	56	.829	.559	1.483
12	.201	.978	.213	57	.839	.545	1.540
13	.225	.974	.231	58	.848	.530	1.600
14	.242	.970	.249	59	.857	.515	1.664
15	.259	.966	.268	60	.866	.500	1.732
16	.276	.961	.287	61	.875	.485	1.804
17	.292	.956	.306	62	.883	.470	1.881
18	.309	.951	.325	63	.891	.454	1.963
19	.326	.946	.344	64	.899	.438	2.050
20	.342	.940	.364	65	.906	.423	2.145
21	.358	.934	.384	66	.914	.407	2.246
22	.375	.927	.404	67	.921	.391	2.356
23	.391	.921	.425	68	.927	.375	2.475
24	.407	.914	.445	69	.934	.358	2.605
25	.423	.906	.466	70	.940	.342	2.747
26	.438	.899	.488	71	.946	.326	2.904
27	.454	.891	.510	72	.951	.309	3.078
28	.470	.883	.532	73	.956	.292	3.271
29	.485	.875	.554	74	.961	.276	3.487
30	.500	.866	.577	75	.966	.259	3.732
31	.515	.857	.601	76	.970	.242	4.011
32	.530	.848	.625	77	.974	.225	4.331
33	.545	.839	.649	78	.978	.208	4.705
34	.559	.829	.675	79	.982	.191	5.145
35	.574	.819	.700	80	.985	.174	5.671
36	.588	.809	.727	81	.988	.156	6.314
37	.602	.799	.754	82	.990	.139	7.115
38	.616	.788	.781	83	.993	.122	8.144
39	.629	.777	.810	84	.995	.105	9.514
40	.643	.766	.839	85	.996	.087	11.43
41	.656	.755	.869	86	.998	.070	14.30
42	.669	.743	.900	87	.999	.052	19.08
43	.682	.731	.933	88	.999	.035	28.64
44	.695	.719	.966	89	1.000	.018	57.29
45	.707	.707	1.000	90	1.000	.000	----

BIOGRAPHICAL SKETCH

HUGO LEECH

Having served as a Captain of an LTD supplying the Islands off the coast of Scotland, Hugo undertook flying training with the British Army in 1963 and functioned in the capacity of an operational pilot flying helicopters in northwest Europe and South America. He continued flying training at the Central Flying School of the RAF in 1966 and instructed at the School of Army Aviation, Middle Wallop, and at the Operational Training Unit in Kluang, Malaysia.

Emigrating to Canada in 1969, he joined Northern Helicopters of Abbotsford, British Columbia, and flew for six years in the B.C. interior and the Northwest Territories. During this period he was also CFI of Northern's Helicopter School.

Mr. Leech joined Transport Canada in 1974 to become the helicopter flight training specialist. As such he is responsible for co-ordinating helicopter flight training standards and techniques across Canada, and for directing the annual Helicopter Instructor Refresher Courses.

Among his many accomplishments, Mr. Leech is also a musician and as such has achieved distinction in the musical comedy troop known as the BNA Act which has appeared in locations such as the National Arts Centre in Ottawa.

BIOGRAPHICAL SKETCH

DR. OLAF SKJENNA

Born in Medicine Hat, Alberta, Dr. Skjenna graduated from the University of Alberta in 1967 following which he served in the RCAF as a Flight Surgeon for four years. During his tenure in the Armed Forces, he became a military parachutist and a fixed-wing and helicopter pilot.

Dr. Skjenna left the Canadian Armed Forces in 1972 and became the Regional Aviation Medical Officer of the Central Region in Winnipeg. In 1974 he obtained his Diploma in Aviation Medicine from the RAF Institute of Aviation Medicine in Farnborough, where he returned as a guest lecturer in 1975 and 1976.

Dr. Skjenna moved to Ottawa in 1976 and became the Deputy Director of Civil Aviation Medicine. During his career, he has participated in the investigation of numerous aircraft accidents and developed a special interest in the plight of the helicopter pilot.

Married with four children, Dr. Skjenna's main interests include flying (he holds a commercial helicopter licence), sailing, music and wood carving.